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Synthesis of Green Hydrocarbons Using the AIR TO FUELS™ Technology

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Synthesis of Green Hydrocarbons Using the AIR TO FUELS™ Technology

Abstract
Our AIR TO FUELS™ project is based off a process designed by Carbon Engineering by the same name which seeks to synthesize liquid fuels from capture carbon dioxide captured from the atmosphere. The need for reduced greenhouse gases in our atmosphere is more urgent than ever and becoming more dire by the day. Still, our society's reliance on liquid fuels like gasoline, diesel, and jet fuel is deeply rooted in our infrastructure and certainly not changing quickly or soon. The AIR TO FUELS™ process seeks to tackle both of these problems by taking carbon dioxide out of the atmosphere in order to produce 2000 bbl/day of liquid fuels that work with our vast existing petroleum-based infrastructure.

This AIR TO FUELS™ plant can be easily segmented into four different portions of the process, each accomplishing an integral step in the production of synthetic fuels. Perhaps the most important is the carbon capture step, making use of the patented Direct Air Capture technology to strip carbon dioxide from the air and purify it to the level needed for the production of syngas via the water-gas shift reaction. Syngas is then converted to alkanes using the nearly century old Fischer-Tropsch process and these alkanes are purified with a network of flash drums and a distillation column. Products generated from this final step are heavy alkanes (waxes and lubricants) to be sold, light gases to be burned in lieu of fuel gas in several of the gas-fired heaters used in the plant, and pure gasoline and diesel range alkanes, to be sold to refiners who will then blend these alkanes into usable fuels. Due to this final step necessitating the cooperation of oil refineries, it is germane to locate the AIR TO FUELS™ plant near large concentrations of these corporations, which indicates that the Gulf Coast of Texas is a suitable choice. This agrees with other factors such as high humidity, subsidies for renewable energy, and large swathes of available land, and as such, the area near the city of Corpus Christi, Texas is considered ideal.

While the science and engineering behind our AIR TO FUELS™ process design are solid, its economic prospects are not. We hope to sell our product as green synthetic crude oil at $72/bbl, charging a 1.2x premium for both its cleanness (free of heavy metals, NOx, and SOx) and greenness. The total capital investment of our project exceeds $2.2 billion, including $812 million in solar panels to ease our 500 MW electricity costs, $378.5 million in electrolyzers to generate hydrogen, $300 million in catalysts and normal chemical processing equipment, and $6.8 million in high capacity fans for our carbon capture system. On top of the massive capital investment, the daily operating costs of our design far outweigh our daily revenue, guaranteeing our project to be unprofitable. These daily costs come mostly from the utilities - the replenishment of our CO2 absorbing solution and its salts costs $86.74/bbl, and the cost of the remaining utilities (cooling water, steam, refrigerant, etc.) is $55.75/bbl. We hope that the ongoing development of solar panel and electrolyzer technologies alongside improvements in the efficiency of our design could one day make our AIR TO FUELS™ process profitable.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

Abstract

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Department of Chemical Engineering
University of Pennsylvania
311A Towne Building
220 S. 33rd Street
Philadelphia, PA 19104

23 April 2019

Dear Mr. Bruce Vrana, Mr. Stephen Tieri, and Drs. John Vohs and Aleksandra Vojvodic,

Please find attached our CBE 459 Senior Design Project "Air to Fuels Production Facility," proposed by Mr. Stephen Tieri. The final project design makes use of Carbon Engineering's patented Direct Air Capture (DAC) technology, coupled with the well-understood water-gas shift reaction and Fischer-Tropsch reactions in order to produce the requisite 2000 bbl/day of fuel-range alkanes. Additionally, the plant has been designed to operate carbon neutrally, meaning that electricity is provided with solar panels exclusively.

Contained within the body of this report is a preliminary design for such a plant, as well as its economics and projected profitability. Though the plant is smaller than a typical GTL (Gas-to-Liquid) facility, the cost associated with construction is similar due to the high capital cost of renewable energy. Analyses have resulted in a net present value (NPV) of -$2,473,914,200 and a return on investment (ROI) of -17.17%.

Based on the contents of this report, we postulate that several developments in the fuel industry must occur before this plant would become profitable. Such developments include, but are not limited to, greater subsidies for green energy, shortages of oil that increase the price per barrel, or vast increases in the demand for "green" oil. Therefore, we recommend that Carbon Engineering carefully consider the market for this product and the costs associated with a plant of this scale before making a final decision on its construction.

Sincerely,

_____ _____

Tyler Durkin Kyle Kersey

_____

James Paolini

Synthesis of Green Hydrocarbons Using the AIR TO FUELS™ Technology

A Report Prepared by

Tyler Durkin

Kyle Kersey

James Paolini

Advisors

Dr. John Vohs

Dr. Aleksandra Vojvodic

Project Author

Mr. Stephen Tieri

Project Proposal Submitted

23 April 2019

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Section 1

Abstract

Abstract

Our AIR TO FUELS™ project is based off a process designed by Carbon Engineering by the same name which seeks to synthesize liquid fuels from capture carbon dioxide captured from the atmosphere. The need for reduced greenhouse gases in our atmosphere is more urgent than ever and becoming more dire by the day. Still, our society's reliance on liquid fuels like gasoline, diesel, and jet fuel is deeply rooted in our infrastructure and certainly not changing quickly or soon. The AIR TO FUELS™ process seeks to tackle both of these problems by taking carbon dioxide out of the atmosphere in order to produce 2000 bbl/day of liquid fuels that work with our vast existing petroleum-based infrastructure.

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Section 2

Introduction & Objective-Time Chart

Introduction

The past several years have seen a great upsurge in efforts to preserve and protect the environment. It is widely accepted that the percentage of carbon dioxide in the atmosphere has increased substantially over the preceding decades and that such an increase is a contributing factor to the increasing temperatures of the globe. Sovereign nations have met to discuss solving this problem, and such measures have trickled down to corporations that operate in countries that are working towards a long-term solution. One such solution has been put forth by Carbon Engineering, a Canada based firm founded by Dr. David Keith, and their AIR TO FUELS™ technology.

AIR TO FUELS™ is built on the back of several well understood processes as well as another process patented by Carbon Engineering known as Direct Air Capture (DAC). DAC is a combinations of several different reactions intended to first scrub CO_2 from the air and then to isolate the CO_2 in a gas stream. Conventional water gas shift and steam methane reforming reactors are used to produce CO and H_2, a mixture known in industry as syngas. Syngas is then used in a Fischer-Tropsch reactor to produce the straight chain alkanes common in gasoline, diesel and jet fuel. The polymerization product can then be distilled to remove side products and alkanes uncommon in fuel, then sold as the conventional fuel types. A generic block diagram is included in **Figure 1** to provide a brief visual overview to the entire AIR TO FUELS™ process. Each section of this diagram will be further described later in this report.

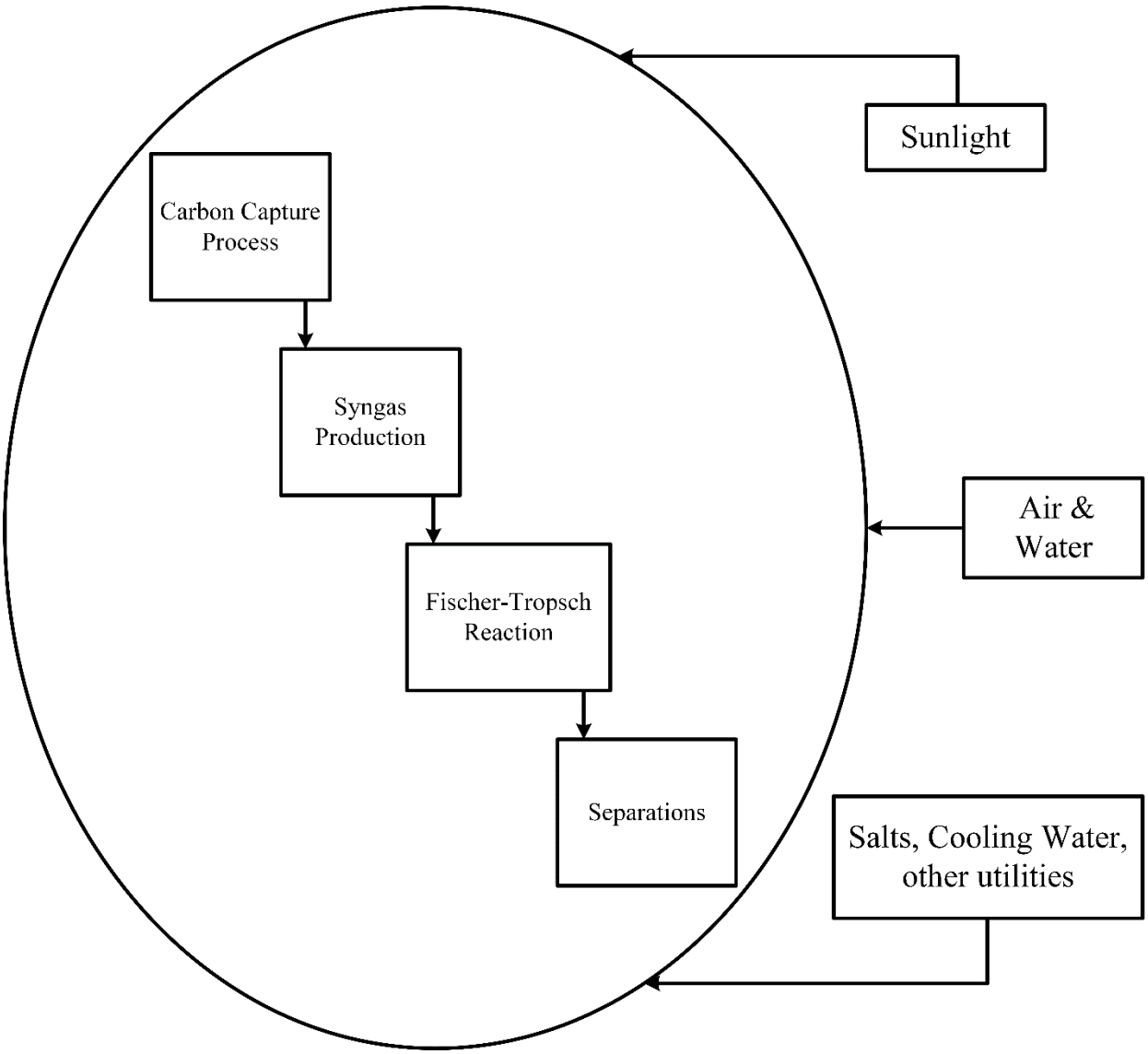


Figure 1: Generic block diagram outlining the stages of the AIR TO FUELS™ process.

Carbon Engineering has already developed a pilot-scale plant for this process and has seen success on the small-scale, but has yet to develop a full-scale version of AIR TO FUELS™. It is desired to work towards the implementation of such a full-scale plant with the production target of 2000 barrels of fuel produced each day. Equally as important as the production targets are remaining as environmentally friendly as possible, in the spirit of Carbon Engineering and

the efforts of the world to reduce CO_2 emissions, and working to make technology like AIR TO FUELS™ economically viable on a large scale.

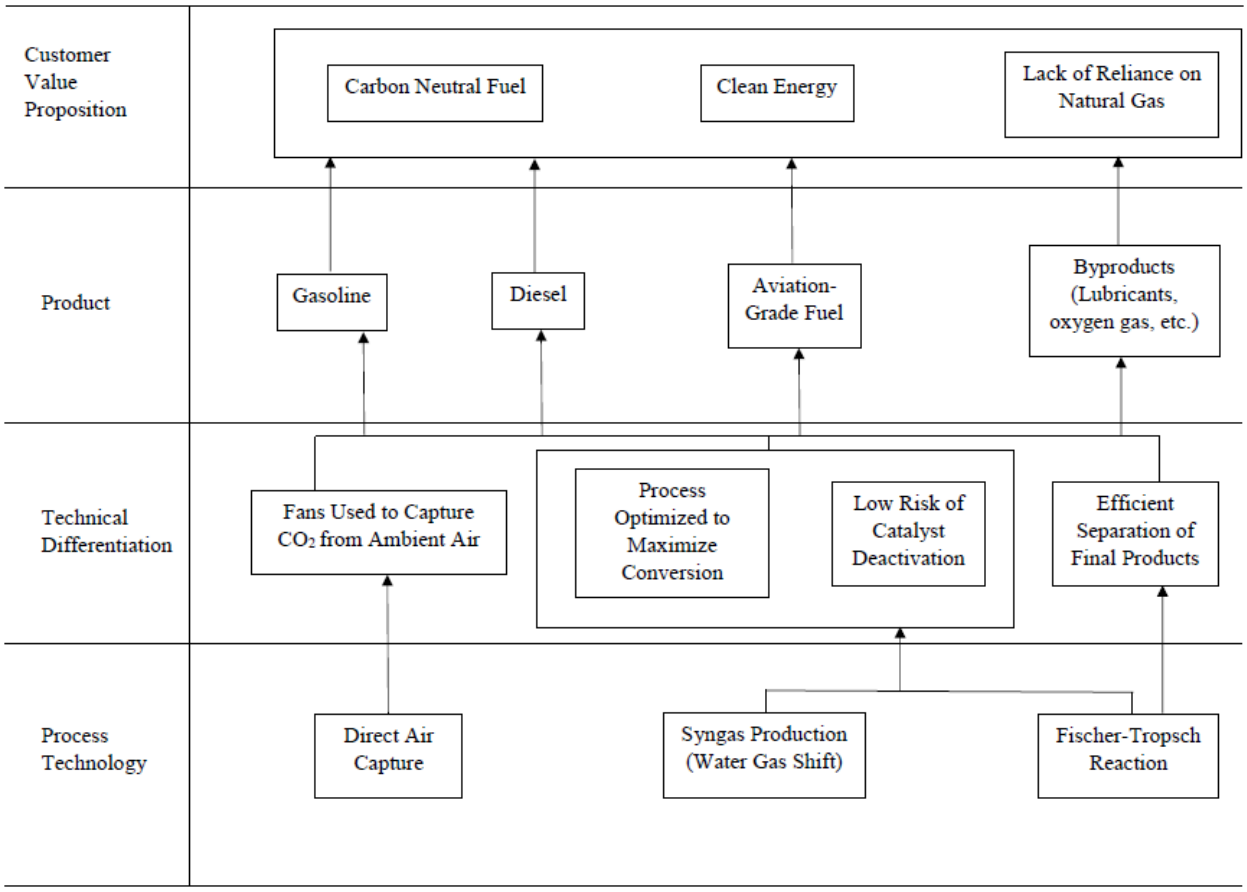
Objective-Time Chart

MONTH	JANUARY:	FEBRUARY:	MARCH:	APRIL:
	Mass balance of process	**Preliminary flowsheet design**	**Finalize flowsheet design**	**Finalize economic analysis**
	Chemistry of process	**Consideration of alternative process steps**	**Preliminary economic analysis**	**Finish report writing**
			Begin report writing	
WEEK	Patent reading	Carbon Capture flowsheet	**SPRING BREAK**	Phoning of companies for reactor/catalyst prices
	Literature searches	Fischer-Tropsch flowsheet		Utilities pricing
	Paper reading			
	Division of labor	Water-gas shift flowsheet	Project economics looked at in detail	Report writing
		Steam methane reforming	Revision of economic mistakes	
	Planning of flowsheet	Mass balance revision	Replacement of "sep" blocks	Finalization of report
	Continuation of paper reading	Separations flowsheet	Flowsheet revision	Finalization of project economics
	Flowsheet began	Preliminary energy balances	Flowsheet essentially complete	Continuation of phoning companies
		Revision of separations	Report writing begins	
DAY	**January Daily Activities**	**February Daily Activities**	**March Daily Activities**	**April Daily Activities**
	Paper reading	Work on flowsheets	Work on flowsheets	Report writing
	Preliminary flowsheet work	Analysis of process alternatives	Report formatting/baseline work	Economic analysis
	Project literature			

Section 3

Innovation Map

Innovation Map



Section 4

Market & Competitive Analysis

Market and Competitive Analysis

It would not be remiss to claim that the world is truly dependent on crude oil. The global demand for crude oil is already enormous in scale and appears to grow or remain essentially constant in each quarter. The International Energy Agency (IEA) reports that in the third quarter of 2018 the global demand for oil was 99.98MM bbl/d, an increase of 1.17MM bbl/d from the 98.81MM bbl/d demand in the second quarter of that same year despite the decrease in demand from Organization for Economic Co-operation and Development (OECD) countries.[1] An increase of over one million barrels each day in between quarters of a year even with the decrease in demand from the western democracies. indicates that the market for crude oil is strong and will continue to grow. Indeed, the IEA predicts that the market will grow by approximately 1.4MM bbl/d in 2019 due to increased demand from various Asian countries.

It remains important to note that the product from the AIR TO FUELS™ process is not typical crude oil. As the AIR TO FUELS™ product is produced using a Fischer-Tropsch reaction, it is composed entirely of highly pure, straight-chain alkanes which are then easily blended into fuels such as the requested gasoline, diesel, and jet fuel. Crude oil contains various impurities (NO_x/SO_x, metals, etc.) that are naturally, undesirable in fuel. In addition, the AIR TO FUELS™ product can be classified as a green fuel, in that the production is entirely carbon neutral. This, once again, creates a distinction between crude oil and the AIR TO FUELS™ product that allows for the argument that demand for such a product can only be somewhat predicted using the demand for crude oil. It is clear that the AIR TO FUELS™ would likely sell

for a higher price, and by extension, could only be properly understood if a market existed for green fuels of a similar ilk.

As carbon capture has grown in popularity over the past few years, it is possible to develop predictions as for the competition that might be faced by Carbon Engineering's AIR TO FUELS™. Those exploring carbon capture, and by extension green fuel, are both start-up companies like Carbon Engineering and ClimeWorks, a Swiss based company that primarily sells captured CO_2 to soft drink companies, and large fuel corporation such as Shell and Chevron. An additional competitor exists in the form of Carbon Recycling International, an Iceland-based company whose primary product is methanol produced from carbon capture, but also produce high cetane diesel. The production of diesel indicates that there is a direct competitor, but due to the locational disparities, it is unlikely that Carbon Recycling International would capture all of the demand for green diesel. Still, the market for green fuel is clearly developing and it is likely that more competitors will emerge in the coming years.

It is also prudent to analyze the current market for the entire distribution of products produced in the AIR TO FUELS™ process that are not fuel components, namely the light gases and the heavier alkanes. Light gases (methane, ethane, propane, and butane), as reported by the IEA, are sold in amounts that contain 1,000,000 BTU of energy when burned. In all cases, crude oil retails for a considerably larger amount of revenue, which indicates that it would be more beneficial to burn these light gases for heating within the AIR TO FUELS™ process. This decision can be made on the basis of several factors, most importantly, that it is cheaper to make use of internal methods to provide energy than to purchase the same gases from an external source. This, coupled with the fairly low demand for methane due to the large amounts of natural gas present in the United States, renders the prospect relatively fruitless.

On the contrary, it is easy to see the value in the sale of the higher molecular weight paraffins produced in the Fischer-Tropsch process as business-to-business (B2B) products. Heavy alkanes are the major component of numerous lucrative products such as engine oils, petroleum jelly, grease, etc.. Petroleum jelly, which is simply composed of these higher alkanes, would be the simplest to prepare due to the AIR TO FUELS™ process already producing all of its constituents and sees use as a lubricant for both industrial and medical purposes. Thusly, the demand remains sufficient for Carbon Engineering to sell some of the heavier alkanes to producers of petroleum jelly, for example Unilever, for roughly 3 to 5 dollars per kilogram as reported by similar large scale sale of wax by Alibaba, a China based site often used for industrial transactions. It is likely that a similar revenue could be expected for the sale of these heavy paraffins for use as engine oil or greases, although the process would require more reforming from the alkane.

The electrolysis of water to produce the hydrogen gas necessary for the Fischer-Tropsch process produces another side product, namely pressurized oxygen gas. Though oxygen is a large component of air, and thus easily available, demand does exist for pure, pressurized oxygen. This demand is not great enough for this oxygen to sell for anything more than approximately 0.1 dollars per ton, but this still proves to be significant considering the massive amount of oxygen produced for the AIR TO FUELS™ process.

Section 5

Customer Requirements

Customer Requirements

Section 5.1: Gasoline

Carbon Engineering's AIR TO FUELS™ process produces only business-to-business (B2B) products, but even so, it is expected that certain requirements be fulfilled in its straight-chain alkanes before they are sold to those who plan to reform them. It is prudent to begin with what will likely prove to be the major final product of the green alkanes, namely gasoline. As reported by the Agency for Toxic Substances and Disease Registry (ATSDR), there are several factors that must be true for a fuel to meet the qualifications of gasoline. A typical measurement of the quality of the fuel is its octane rating, which is a measurement of a fuel's ability to resist engine knocking, a phenomenon caused when the fuel inside the engine burns ignites unevenly. As is well known, gasoline rated as "regular" has an octane rating of 87 out of 100, which represents the lowest octane rating of a fuel that claims to be gasoline - "plus" has an octane rating of 91 and "premium" has an octane rating of 93.[2] Different hydrocarbons naturally have different octane numbers and they must be accounted for when preparing gasoline, which is a blend of hydrocarbons. The ATSDR reports that typical gasoline contains a blend of straight alkanes (such as those produced in the AIR TO FUELS™ process), branched alkanes, cyclic alkanes, olefins, and aromatics.[3] Normal alkanes have relatively low octane numbers and make up a fairly small fraction of gasoline - the vast majority of gasoline is comprised of aromatics and branched alkanes. This is the case, because as reported by the textbook *Fundamentals of Petroleum Refining*, branched alkanes tend to have octane numbers approaching 100, which is ideal for gasoline. Even more ideal is the fact that aromatics like toluene and xylenes have octane ratings of greater than

100, which work to negate the negative octane ratings of normal alkanes like nonane and decane. Of course, the AIR TO FUELS™ process does not produce these hydrocarbons, but they can all be synthesized beginning with straight-chain alkanes that are the final product of the AIR TO FUELS™ process. Refineries would then expect a pure mixture of straight-chain alkanes in the carbon range of 5 - 11 for use in their gasoline blend or their own reformers.

Section 5.2: Diesel

Diesel, much like gasoline, consists of a blend of numerous different hydrocarbons whose identity contributes to the grade of the fuel, which in the case of diesel is referred to as the cetane number. As diesel engines do not have spark plugs, the fuel must be able to ignite under compression alone. Cetane (or hexadecane, under IUPAC naming conventions) is assigned a cetane number of 100 due to the ease at which it ignites when compressed. Typical diesel engines can run properly if a fuel has a cetane number of at least 40, but regulations generally require the cetane number of a blend to be at least 51. Naturally, a higher cetane number would not impede the functionality of a diesel engine, and indeed higher cetane number fuels are associated with a smoother start and less noise (although in some cases, an extremely high cetane number does result in excessive smoking). Diesel contains the types of hydrocarbons as gasoline, namely straight-chain alkanes, branched alkanes, cyclic alkanes, and aromatics. Of course, compounds have a different cetane number than octane number. For instance, aromatics, which have octane numbers of over 100, have cetane numbers approaching zero, while the opposite trend is shown in alkanes. Again, much like gasoline, the producers of diesel will only be expecting the straight-chain alkanes to be provided by the AIR TO FUELS™ process as those are the products of the Fischer-Tropsch reaction. Of course, the particular alkanes in question are different. Alkanes typically useful in

gasoline have lower cetane numbers, therefore, alkanes ranging from dodecane to eicosane are typically the most useful and would be provided to diesel refiners with high purity from the AIR TO FUELS™ process. The remaining hydrocarbons that are blended with these alkanes (examples include biphenyl and 2-methylnonadecane) would be produced or purchased by the reformer.[4]

Section 5.3: Jet Fuel

Unlike gasoline and diesel fuels, jet fuel is typically classified based upon its physical properties as opposed to a concept like an octane or a cetane number. For example, the jet fuel is generally classified as Jet A or Jet B. Jet A (or its derivative, Jet A-1) consists of carbons in the kerosene region (octane through hexadecane) and Jet B typically consists of carbons in the naphtha region (pentane through pentadecane).[5] In the United States and the major cities in the south of Canada, Jet A is the typical fuel because of its relative safety when compared to Jet B (which is more volatile due to its composition favoring light hydrocarbons). Jet B is only needed in very cold climates like Russia and Northern Canada due to its lower freezing point. Though the AIR TO FUELS™ process produces straight-chain alkanes in both the naptha and the kerosene range, producers will only expect to be provided with hydrocarbons in the kerosene range because of the plant's location, where only Jet A is utilized by the aviation industry. Requirements for classification of an aviation fuel as Jet A are fairly simply, namely it must have a freezing point of -40 ^{o}F and a flash point of 100 ^{o}F and a density of approximately 6.84 lb/gal, although of course, these qualifications will be met by the refinery.[5]

Section 5.3.1: Avgas

Although Jet A and Jet B are far more common, there are a small number of aircraft that operate using Avgas, a similar fuel with the principal difference being the fact that Avgas is still a leaded fuel. Avgas comes in two main types, 100 and 100 LL, where the only difference is again, lead content, with the 100 LL fuel classification serving as the "low leaded" fuel (containing approximately 0.56 g/L of lead).[6] Avgas is typically considered an octane based fuel, which implies that the composition of hydrocarbons that would be sent to the Avgas producers would be the naphtha mixture that would be utilized in Jet B or gasoline, which, indeed, is produced by the AIR TO FUELS™.

Section 5.4: Side Products

The nature of the Fischer-Tropsch polymerization mechanism for the series of syngas to fuel reactions dictates that there will not be just gasoline, just diesel, etc., or complete conversion of our feed. In reality, incomplete conversion will lead to a series of side products. We can take advantage of some of these for additional profits.

Section 5.4.1: Lubricants

Lubricants are a class of straight-chain alkanes (C21+) that are typically not useful in fuel refining due to their physical properties - the vast majority of these are in the solid phase at room temperature. The AIR TO FUELS™ process, as noted earlier, is based on the Fischer-Tropsch process and produces a large distribution of paraffins, some of which are these industrial lubricants. Common examples of these lubricants are petroleum jellies, greases and engine oil. In some cases, the AIR TO FUELS™ plant directly produces each

of the constituents of the product, but in others, like greases, it only produces the building blocks. Again, as only B2B products are considered, this is not a problem. The only requirement lubricant producers would have would be high purity of these heavy alkanes, which is never an issue in a synthetic fuel plant.

Section 5.4.3: Oxygen Gas

The requirements that customers would have for the purchase of oxygen gas are relatively straightforward. Oxygen is available as a fraction of air for no cost, so oxygen from the AIR TO FUELS™ process would need to be pure and pressurized to sell for any amount at all.

Section 6

Critical to Quality (CTQ) Variables

Critical to Quality (CTQ) Variables

The final products of the AIR TO FUELS™ process, as mentioned in earlier sections of this report, are extremely pure alkanes for later use in fuel refining. Several integral aspects of this product must be fulfilled for the product to be considered for purchase and use by the major companies responsible for the refining of the alkanes. The most important criteria for the series of alkane products is their purity and composition. Gasoline refiners have no use for alkanes lighter than pentane because of their gaseous state at standard conditions. Alkanes like butane are also typically used as filler in gasoline due to their low octane number allowing for cheaper aromatic compounds (with high octane numbers) to be included. The product stream should thus contain as little filler alkanes as possible. Similarly, the heavy alkanes stream (C21-C30) that will go on to be sold should be comprised of as few light alkanes outside of this range as possible.

The delivery pressure and temperature of the product stream are also important. Fuel is typically stored at standard pressure and temperature, which implies that the AIR TO FUELS™ products must be stored and delivered at such conditions.

Section 7

Product Concepts

Product Concepts

Section 7.1: Fuel Products

When given this problem statement originally, the challenge was to design a facility to operate at a production capacity of 2,000 standard barrels of any combination of gasoline, diesel, and jet fuel to achieve the most profit. Each of these types of hydrocarbon fuels encompasses a different carbon chain length range, and, necessarily, slightly different cuts within the distillation range. However, within a gallon of gasoline the Agency for Toxic Substances and Disease Registry reports the quantities of straight-chain alkanes present to be only within the 4-8% by volume range.[3]

Our initial approach to this project is to draw upon existing gas-to-liquid technology in the form of the Fischer-Tropsch (FT) process. However, while the FT synthesis allows for efficient conversion of syngas ($CO+H_2$) to liquid fuels, the nature of the polymerization mechanism and choice of catalyst (Cobalt, in our process) lead to a product stream composed entirely of straight-chain hydrocarbons from C1 onward, the relative percentages of each of these given by the mathematical Anderson-Schulz-Flory distribution.[7] Due to the large disparity between the volume of *n*-alkanes required in gasoline (among other fuel types) and the products produced by the FT synthesis, we would need a large amount of refining. The same source quotes the gasoline volume percentages of isoalkanes and aromatics to be 25-40% and 20-50%, respectively.[3] Each of these products can be generated from *n*-alkanes, yet isomerization and aromatization reactions to form these products are energy intensive and would need to be run on a large scale. We believe the breadth of refining operations required to blend our own gasoline after synthesizing our own

straight-chain alkane starting materials (as opposed to obtaining these from petroleum fractional distillation using crude oil) is out of the scope of this project. The amount of downstream, post FT complexity would not be realistic given the time frame of this project, and the byproducts from the refining operation would increase the amount of CO_2 required from our Direct Air Capture process would vastly move the necessary amount of air out of what could feasibly be installed.

As such, our team as decided to define the product of this project to be the dry and purified straight-chain alkanes produced by the FT reactor. More will be discussed on the intricacies of the markets for these hydrocarbons, but we believe a green source of hydrocarbons, which would be otherwise obtained from environmentally-damaging oil drilling remains true to the spirit of this project.

Section 8

Superior Product Concepts

Superior Product Concepts

Section 8.1: Fuel Products

Having discussed the potential product concepts in **Section 7**, we have decided that the best course of action is to sell the Fischer-Tropsch liquid and solid hydrocarbons as our primary product. The low-boiling gases C1-C4 and any unreacted syngas that are initially recovered before the distillation process will be used for internal process equipment heating. The high-boiling alkanes in the C21-C30 range will be sold as precursors to industrial lubricant manufacturing facilities, where they will be reformed into products such as petroleum jellies and lithium greases. The traditional oil range of C5-C20 will be further divided into two sections, with the lighter cut (C5-C11) and heavier cut (C12-C20) sold to petroleum refineries companies for further processing into traditional gasoline and diesel fuels, respectively.

Section 8.2: Oxygen

As a byproduct of our water electrolysis system for hydrogen generation, a stream of pure oxygen is generated in half the capacity as our hydrogen. This oxygen is generated at high pressure from the electrolysis unit and will be sold as a separate by-product of our fuel synthesis system.

Section 9

Competitive Patent Analysis

Competitive Patent Analysis

Section 9.1: Intellectual Property (IP) Assessment

Within the growing field of carbon capture and storage (CCS), an interest is developing in not only sequestering carbon dioxide emissions but instead transforming them into value-added products. In addition to Carbon Engineering, off whose technology our design is based, three other major players have begun to use carbon dioxide sequestration for the either sale as a concentrated stream or for synthesis of higher-value products: Climeworks AG, Carbon Recycling International, and Royal Dutch Shell.

Section 9.1.1: Climeworks AG

Climeworks AG, a Swiss-based company, captures CO_2 from the air using a modular bank of fans similar to that of Carbon Engineering. The company purifies this CO_2 and sells the carbon dioxide itself as its product, rather than using it as a feedstock for a downstream process. Their market is typically agricultural industries, beverage companies, etc. who require high purity carbon dioxide.[8]

While their fan bank is similar in architecture, the method by which the carbon capture occurs is considerably different. Within each fan unit, a fan acts to provide the pressure needed to move the air through the unit. The air passes through a winding path to ensure a high contact area with a granulated fibrillated cellulose packing, which selectively adsorbs the CO_2 from the air. This cellulose material is functionalized with molecules such as 3-aminopropylmethyldiethoxysilane, though many of starting materials of similar

molecular geometry and functionality are described. The primary amine on one end of the propane backbone allows it to couple to the cellulosic fiber in the packing. On the other end, the methyldiethoxysilyl group is subsequently hydrolyzed, such that the two ethoxy groups become hydroxyl groups, releasing two equivalents of ethanol. The now-siloxyl functional groups on the free end of this molecule can act as the adsorbent, interacting with the CO_2 in the incident air stream to perform the scrubbing operation through acid-base chemistry.[9] This adsorption process occurs at ambient temperature and pressure.[10]

With CO_2 adsorbed on this packing, Climeworks uses an elevated temperature and reduced vacuum pressure to desorb the CO_2 and collect a pure stream. Within the shroud containing the adsorption media, there are mechanical seals that can isolate the packing, at which point the pressure is reduced likely to the mbar level when the adsorbent packing's temperature is raised to the 90-120°C range (1 mbar absolute is the pressure limit of the vacuum chamber at the specified temperature). This mechanical switching allows the incoming air and exiting CO_2 streams to be isolated and recovered. According to one of Climeworks' CO_2 removal patents, the desorbed gas stream is at least 50% CO_2.[11]

Section 9.1.2: Carbon Recycling International (CRI)

Carbon Recycling International (CRI) was founded in 200, is based in Reykjavik, Iceland, and uses carbon dioxide sequestration, combined with hydrogen generated from renewable solar energy, to create green methanol.[12] This product, Vulcanol™, is sold as a high-octane fuel ingredient or for further production into synthetic fuels. Electrolysis is again used for hydrogen generation, with the electricity coming from green sources (solar and wind).[13] The company describes that its George Olah plant is located next to a

geothermal energy source and that the flue gas - steam emissions from power generation - are the source of this CO_2.[14] The concentration or method of capture are not discussed in any of their patent information, which is already quite scarce. The company also lists on their website the future initiative to develop capture and synthesis systems to operate downstream of steel manufacturing plants. The flue gases from steel furnaces would be their source of feedstock in this case.[15] A pilot-scale production facility is under construction and aims to be completed in late 2019, with a mid-2020 demonstration date.[16]

Section 9.1.3: CANSOLV (Royal Dutch Shell)

CANSOLV is a CO_2 capture technology used by Shell to remove CO_2 concentration of natural gas and coal-fired power plant flue gas streams in the presence of NO_x, SO_x, and other pollutant material. This method is predicated on the use of an aqueous solution of amine-based mass transfer agents and other oxygen scavengers and inert salts) to do the absorption.[17] These amines are typically tertiary in nature and range and are typically derived from a linear or cyclic diamine, though ammonia derivatives are also used. Regardless, all of these amines are functionalized with multiple acidic alkoxy groups (hydroxyethyl, hydroxypropyl, alkylsulfonic acids, etc.) such that the CO_2 reacts with the OH functional group to form a bicarbonate ion that remains bound to the amine structure, similar to Climeworks' amine-functionalized cellulose scrubbing method. Due to the slower kinetics of CO_2 adsorption via this medium, activators in the form of secondary or primary amines are added to improve CO_2 uptake.

The gas is contacted with the liquid by flow through a packing. After being washed with water, the lean gas is vented. The CO_2 is released from the amine adsorbent by contact

with a stripping gas at elevated temperature and pressure (less than 3 bar abs.) in a countercurrent stripping column, at which point the amine solution is recycled back to the absorber. This system can also be used to remove NO_x and SO_x from the streams through slight modification of the chemical composition of the absorbing solution.[17][18]

In the case of installations downstream of power plants or furnaces, with CO_2 flue concentrations ranging from 3-20% by volume, the CANSOLV process is able to consistently reach 90% capture rates. In the pilot scale for similar CO_2 concentrations, removal ranged from 75-90%. One of the facilities using this technology, which began operation in 2009, was designed to remove CO_2 on the scale of 50 tons per day.[19] This scale (an 1-100 ton per day scale) appears typical of this technology, given their clientele and feedstock source.

Section 10

Preliminary Process Synthesis

Preliminary Process Synthesis

Section 10.1: CO_2 Capture Systems

The dilute concentration of CO_2 in ambient air (around 400 ppm) and the scale of this proposal naturally necessitate that a large amount of air be moved. In addition to the Carbon Engineering designs, which make use of multiple modular banks of fans to accomplish the capture, we explored the use of cooling towers as a large-scale surrogate for an intricate system. The two versions, natural and forced draft, are discussed in more detail below.

Section 10.1.1: Natural Draft Cooling Tower

The natural draft cooling towers commonly seen in many nuclear power plants and other large-thermal load facilities operate on passive cooling methods to move very large volumes of water, up to an order of 100,000 tons of water per hour.[20] This is accomplished by piping the hot cooling water into the cooling tower, then allowing to to fall as a film from the pipes. The thin film area exposed to ambient conditions allows passive heat exchange with the environment to occur, and the generated steam is carried up and out of the column in the form of the familiar plume. The rising steam due to the temperature differential causes a lower pressure at the bottom of the column, and air flows in through the trussed structure to give the natural draft. The now-cooled water is collected at the bottom of the tower, replenished with fresh cooling water, and recycled back for re-use.[21]

In the case of these towers, the guiding principle is to cool as much water as

possible in the most efficient manner. As such, the natural draft generated helps remove the steam but has no other role. Our carbon capture system has the opposite set of requirements: we wish to move a large amount of air but use comparatively little scrubbing solution. Implementing this design into our carbon capture system, even with multiple towers, the induced natural draft would not be powerful enough to move the amount of air needed, which is on the order of 700,000 cubic feet per second.

Section 10.1.2: Forced Draft Cooling Tower

Forced-draft cooling tower units are modular, with each capture unit having its own fan. Such a setup is more in line with our capture system, yet the design faces a similar issue in that even with the forced draft, the tower system is still optimized for large liquid flow and low air flow. The unit typically has a high-surface area packing to increase the contact between the airflow and the falling water, so it may be possible to implement some modification on this design as an alternative.[22] We have considered this but chose to follow the designs discussed in Carbon Engineering

Section 10.2: Process Modifications for the CO_2 Direct Air Capture System

Within Carbon Engineering's existing Direct Air Capture technology the company uses two separate bases - KOH and $Ca(OH)_2$ - in the scrubbing of the carbon dioxide from the air. The KOH performs the initial scrubbing of the CO_2 from the air through direct contact, and the gas is stored in the form of K_2CO_3. Through a double-displacement reaction in a separate reactor, the carbonate is transferred to calcium using $Ca(OH)_2$.

As a way to simplify this process, we looked into ways of performing this separation using only one of these bases. With only one base used, rather than two, one of the loops could be omitted, greatly simplifying the chemistry, as well as could the utility, energy, and capital requirements. As such, we explored three alternatives: the Benfield process, the amine-promoted Benfield process, and a $Ca(OH)_2$-only capture system.

Section 10.2.1: The Benfield Process

The Benfield process is commonly used in gas sweetening operations. The process uses potassium carbonate (K_2CO_3) to react with CO_2 and water in the incoming air stream to form an equilibrium with potassium carbonate ($KHCO_3$). A sour gas stream is then introduced in a separate absorption unit, in which the K_2CO_3 reacts with the H_2S gas to convert to KHS and $KHCO_3$.[23][24]

While this process has considerable industrial precedent for CO_2 removal from flue or natural gas streams, the carbonate or bicarbonate base is much weaker than the hydroxide bases Carbon Engineering uses for their Direct Air Capture technology. In streams where CO_2 and H_2S are in much higher concentrations (say on the order of 1-5%), then it is rational to use this process. However, the weaker nature of a carbonate base than a hydroxide base means that the kinetics of the acid-base chemistry with CO_2 and H_2S will be much slower. Additionally, the solubility of the carbonate solutions are low, which would decrease the ability to capture CO_2. There is, of course, the possibility of increasing the pressure and temperature of the scrubbing units. This option is capped by the boiling point of water, since these basic solutions are aqueous. The solubility and kinetics thus can only be increased so much.

In our process, slow kinetics are unfeasible. As a result of the quantities of air at 400 ppm CO_2 we will need to move through absorption units (see **Section 15: PFD & Material Balances** for more information), we require an absorption mechanism with fast reaction between the base of choice and the CO_2. This will allow a large and rapid fractional conversion of the CO_2. The Benfield Process by itself was thus rejected as an alternative for the system Carbon Engineering describes in its patent.[25]

Section 10.2.2: The Amine-Promoted Benfield Process

One way to increase the acid-base kinetics of the Benfield process is to add a promoter. Often, this is an amine. The reaction of the CO_2 with the K_2CO_3 in the presence of water forming $KHCO_3$, as well as the reaction between CO_2 and H_2O leads to some dissociation to $HCO3^-$. The amine in the solution reacts with this bicarbonate ion to form the carbamate ion, which is able to increase the amount of CO_2 captured. Piperazine, a cyclic diamine is often used, as it can capture two CO_2 molecules per molecule of amine.

However, an analysis of this method and published ASPEN Plus modelling simulations show that this approach is still better suited for CO_2-rich streams, rather than our low-concentration air streams.[24] Although the kinetics can be improved noticeably by the addition of an amine promoter, the cost of purchasing this amine and using it to improve an already-unfeasible system for this CO_2 capture was not rational when compared with Carbon Engineering's use of KOH.

Section 10.2.3: $Ca(OH)_2$ as the Only Base

Finally, we examined the use of $Ca(OH)_2$ as the only base in this capture process, as it participates in the double-displacement reaction between K_2CO_3 and $Ca(OH)_2$ in Carbon Engineering's process patent. Due to the limited solubility of $Ca(OH)_2$, this approach was discarded. Low solubility introduces a solid-to-liquid phase transfer before reaction chemistry can occur, which would greatly diminish our ability to remove CO_2 efficiently, not to mention adding additional solids processing equipment.

Section 10.3: Syngas Production Methods

Syngas, composed of carbon monoxide (CO) and hydrogen (H_2), is the fuel for the Fischer-Tropsch synthesis method. Several methods are commonly used for generation of this gas mixture but vary depending on the feedstock used, the desired ratio of CO to H_2, etc. While the reverse Water-Gas Shift (rWGS) is used in our process, we discuss three alternatives below. Each of these uses methane as a reactant for syngas formation. This methane, if used, would come from any of two sources: either recycling of the low-boiling gases out of our FT product distillation system or purchasing of green methane or renewable natural gas (**Section 21**). Renewable resources would still be used, despite the feedstock being a hydrocarbon.

Section 10.3.1: Steam-Methane Reforming (SMR)

Steam-methane reforming is the most promising possibility for the use of methane to generate syngas in our process, since we would readily have access to the water required for the oxidation operation, and the catalyst is a cheap Ni on Al_2O_3 support. The high temperature steam should serve as a sufficient oxidant to prevent coking, yet carbon

deposition is still a concern when using nickel. We found that the design of a full-scale SMR plant to supplement the reverse water-gas shift facility was out of the scope of this project, as the facility itself requires many sub-facilities for further recycle, processing, processing. We have instead decided to focus our attention on the reverse water-gas shift system for syngas production.

Section 10.3.2: Dry Methane Reforming (DMR)

In dry methane reforming, the methane is contacted with carbon dioxide directly in the presence of a catalyst to generate an equimolar mixture of carbon monoxide and hydrogen). While this is an appealing process for our conversion needs, it requires a stoichiometric amount of methane, which we would need to purchase from a renewable source. More troubling, however, is that there is not one particularly well-established catalyst for this process, and ongoing research is focused in this area. Some of the common choices include noble metals, nickel, and cobalt on a variety of oxide supports.[26][27] For our reforming processes, we are avoiding any noble metal catalysts due to their high cost. Cobalt faces the same cost issue, but we must use this for later Fischer-Tropsch to achieve our desired product distribution. Finally, the DMR reaction typically run at temperatures in excess of 640°C, and thus the high carbon ratio in our feedstock poses a coking hazard on a nickel catalyst at these temperatures, which would require the catalyst be replaced or regenerated more often than desirable.[27] Finally, the equilibrium of the reaction will cause some of the hydrogen product to react with the unreacted CO2 via the reverse water-gas shift mechanism to generate water, which is an undesirable product for dry reforming.[28]

Section 10.3.3: Autothermal Reforming (ATR)

Autothermal reforming combines the SMR reaction discussed in **Section 10.3.1** and a partial oxidation reforming step (which converts CH_4 to CO and $2H_2$ in the presence of oxygen). This method relies on heat being supplied to the reaction in the form of elemental oxygen, either with air or a purified O_2 stream.[29] For our system, we would have a stream of pure oxygen coming from our electrolysis system, which could be fed into this reactor. Air is often used, but the inert N_2 would increase the size of our reactor and energy requirements due to the lower feed concentration of elemental oxygen and the heat capacity of the nitrogen, respectively. A common catalyst is Ni supported on Al_2O_3, but more expensive metals (Rh, Pd, Pt, and Co) have also been investigated.[30] We would be confined to Ni for cost purposes, but the coking risk is lower due to the use of elemental oxygen as our oxidizing agent, so long as the proper C:H ratio and reaction temperature are carefully monitored. We have, for similar reasons to SMR, decided that this approach is out of the scope of this project.

Section 10.4: Distillation Setups

Several methods of construction of a mechanism for the separation of the final alkane products were evaluated before the final selection was made. Earlier models were quite inefficient due to the majority of the products traveling through the process in the vapor phase. This necessitates the use of both compressors and pipes large enough to handle gaseous volumes, both of which needless increase the cost of the process. It is both simpler and cheaper to pump liquid than to compress gas. Earlier designs were also inefficient in the separation of the alkane products. Initially, separation was attempted to be achieved directly at the cutoff point for each

type of fuel. This does not make good use of natural points in which the alkanes are easiest to separate, and as such, the ensuing separation was not particularly clean and required more distillation columns than is necessary. It is also possible to exploit the liquid state of the higher alkanes for separation with a simple flash drum, which was not recognized in the earliest models of this process. The final setup is both more energy and monetarily efficient than the first designs.

Section 10.5: Water Removal from Fischer-Tropsch Products

The water byproduct of the Fischer-Tropsch reaction is not necessary for any sort of fuel. In fact, water proves to be a detriment when distillation is attempted due to the existence of an azeotrope between water and octane limiting the use of normal distillation. As such, several methods for water removal were considered before the final choice was made.

Section 10.5.1: Membrane Separation

Several prominent fuel producers (examples include Chevron) make use of a membrane separation mechanism to remove water.[31] In a manner similar to typical membrane separations, there exists a side of the membrane rich in water vapor and a side containing less vapor. A hydrogen sweep gas passes over the the product gas from the Fischer-Tropsch reactor and helps the water vapor through the membrane, which is designed for the purpose of allowing water molecules to pass. This sweep gas, now rich in water vapor, is removed from the other side of the membrane and released into the atmosphere. Though quite efficient at removing water, this option was rejected due to the cost disparity between it and the eventual choice.

Section 10.5.2: Sasol Heat Exchanger Network

Sasol Limited, the world leader in synthetic fuel production, with more than half a century of experience with the Fischer-Tropsch process, utilizes a fairly standard method for water removal which they claim is highly efficient. In their separation, the product gas from the Fischer-Tropsch reactor is cooled with a successive three heat exchangers. After each exchanger, any liquid is removed from the product stream and any water in the resulting liquid is easily separated out due to the difference in polarity of the alkanes and water.[32] This process forms the basis of the water separation mechanism that was chosen, but due to the lack of data regarding the conditions of the three heat exchangers, could not have been used to the best of its ability in the AIR TO FUELS™ process.

Section 10.5.3: Glycerol Absorption

Glycerol (propane-1,2,3-triol) is a very hydrophilic organic alcohol that, as such, is able to extract water from organic solutions with ease. Knowing this, an possible setup for the removal of water is an absorption tower where the gas to be purified is the Fischer-Tropsch product and the liquid is glycerol.[32] Unfortunately, this absorption process removed more than just water from the product stream: an unacceptable amount of product is lost to the glycerol which renders this mechanism infeasible.

Section 10.5.4: Alternative Temperature Decanting

The most efficient mechanism for the separation of water from the alkane product is to take advantage of the differences in polarity between the water (a highly polar molecule) and the hydrocarbons (highly nonpolar). This decanting step achieves higher

efficiency at lower temperatures. Earlier decanter models indicate that the best separation of water occurs at approximately 20°C, but a temperature that low is inefficient, as the product must be heated again for the next separation step and the degree of separation is seen to not be terribly affected by slightly higher temperatures.

Section 11

Assembly of Database

Assembly of Database

The AIR TO FUELS™ process involves a multitude of chemical reactions across the four major subprocesses of the facility. For convenience, these are shown below, organized by section of the process. Enthalpic data is also included above each reaction.[25] For data on the physical properties of the numerous chemicals used in these reactions, please see the Safety Data Sheets in **Appendix C**.

Section 11.1: Carbon Capture

$$CO_2\ (g) + 2KOH\ (aq) \xrightarrow{\Delta H = -96\ kJ/mol} K_2CO_3\ (aq) + H_2O\ (l)$$

$$K_2CO_3\ (aq) + Ca(OH)_2\ (aq) \xrightarrow{\Delta H = -6\ kJ/mol} 2KOH\ (aq) + CaCO_3\ (s)$$

$$CaCO_3\ (s) + Heat \xrightarrow{\Delta H = +165\ kJ/mol} CaO\ (s) + CO_2\ (g)$$

$$CaO\ (s) + H_2O\ (g/l) \xrightarrow{\Delta H = -64\ kJ/mol} Ca(OH)_2\ (s)$$

Section 11.2: Syngas Production

Water Electrolysis	$2\ H_2O\ (l)$ + Electricity	$\xrightarrow{\Delta H = +286\ kJ/mol}$	$2H_2\ (g) + O_2\ (g)$
	$2\ H_2O\ (g)$ + Electricity	$\xrightarrow{\Delta H = +242\ kJ/mol}$	$2H_2\ (g) + O_2\ (g)$
Water-Gas Shift	$H_2\ (g) + CO_2\ (g)$	$\rightleftharpoons^{\Delta H = +41\ kJ/mol}$	$CO\ (g) + H_2O\ (g)$
Steam Methane Reforming	$CH_4\ (g) + H_2O\ (g)$	$\rightleftharpoons^{\Delta H = +206\ kJ/mol}$	$CO\ (g) + 3H_2\ (g)$
Partial Oxidation Reforming	$CH_4\ (g) + ½O_2\ (g)$	$\rightleftharpoons^{\Delta H = -36\ kJ/mol}$	$CO\ (g) + 2H_2\ (g)$
Dry Methane Reforming	$CH_4\ (g) + CO_2\ (g)$	$\rightleftharpoons^{\Delta H = +247\ kJ/mol}$	$2CO\ (g) + 2H_2\ (g)$
Autothermal Reforming	$CH_4\ (g) + ½xO_2\ (g) + yCO_2\ (g) + (1\text{-}x\text{-}y)H_2O\ (g)$	$\rightleftharpoons^{\Delta H = \sim 0\ kJ/mol}$	$(y+1)CO\ (g) + (3\text{-}x\text{-}y)H_2\ (g)$

It should be noted that only the top two reactions are used in the AIR TO FUELS™ process, though alternatives for hydrogen and syngas production are evaluated in **Section 10.3**.

Section 11.3: Fischer-Tropsch Reaction

$$CO\ (g) + 2H_2\ (g) \xrightleftharpoons{\Delta H = -152\ kJ/mol} (-CH_2-) + H_2O\ (g)$$

Section 12

Process Flow Diagrams (PFDs) & Material Balances

Process Flow Diagrams (PFDs) & Material Balances

For ease of understanding and to allow for the description of each diagram as a separate portion of the plant, the process flow diagram for the AIR TO FUELS™ process has been split into four separate blocks. These are: carbon capture (**Section 12.1**), syngas production (**Section 12.2**), the Fischer-Tropsch synthesis process (**Section 12.3**), and the product separation (**Section 12.4**). Again, for ease of understanding, the carbon capture system has been further segmented into four separate blocks, each accomplishing a unique purpose in the carbon capture process. Included in the Appendix of this report are Aspen results and reports (blocks, streams, convergence, etc.).

Also included in this section are the material balances on each of the aforementioned process blocks. It is important to note how the initial calculation for the required amounts of starting were devised. As a sort of "back of the envelope" calculation, the requisite 2000 bbl/day of fuel was assumed to be equal parts gasoline, diesel, and jet fuel and each of these cuts has a density equal to the alkane directly in the middle of the standard hydrocarbon range of the fuel. Of course, the calculated amount of carbon dioxide was too low when this approximation was made as it assumes that all captured carbon dioxide is converted to usable fuel via the Fischer-Tropsch reaction, which, as discussed in previous sections is not the case (see Anderson-Schulz-Flory Distribution). For more accuracy, later models predict the necessary amount of carbon dioxide with the weight fractions of fuel produced by the Fischer-Tropsch reaction, which is more accurate. Then, with the amount of carbon dioxide captured, it is possible to use reaction stoichiometry to calculate the molar requirements of other feed streams. The exception to this

case is the hydrogen feed requirement, which, as per literature sources, a five-fold excess of hydrogen is used to improve conversion.[34] However, this large excess of hydrogen initially is then the only hydrogen added to the process (the remaining reactions that require hydrogen do not require any more than a two-fold excess).

Section 12.1: Carbon Dioxide Capture & Purification

Section 12.1.1: CO_2 Scrubbing

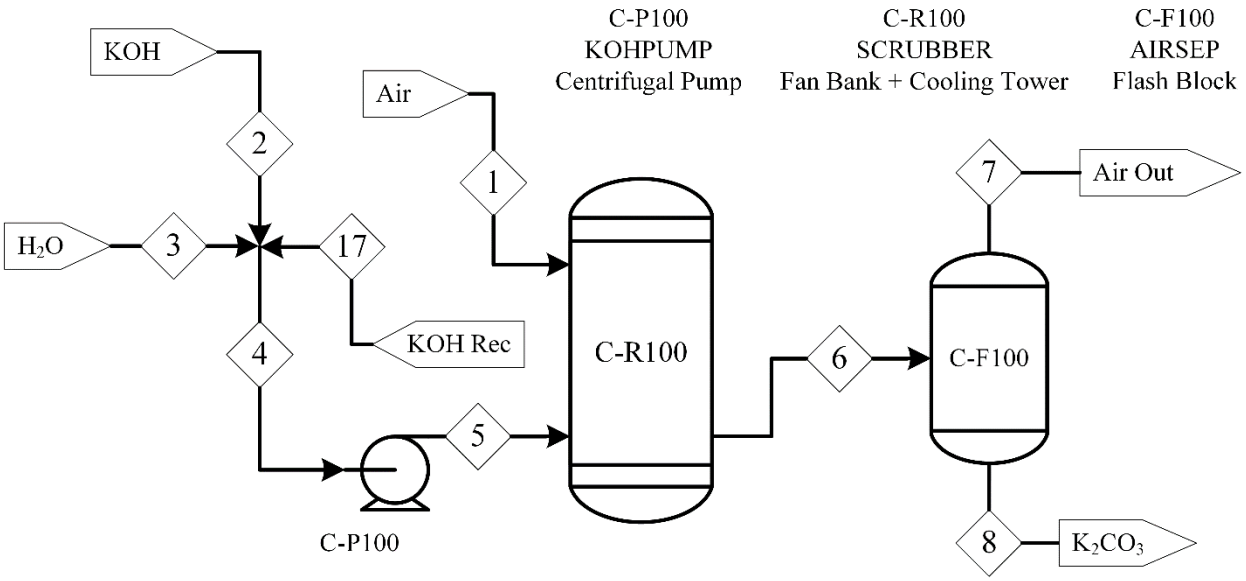


Table 12.1.1: Stream summary table for the carbon dioxide scrubbing process flow diagram. Ion and CISOLID flows (from the ASPEN Electrolyte Wizard) are given.

VISIO Stream ID	1	2	3	4	5	6	7	8	17
Stream ID	AIRIN	KOHFEED	SCRUBH2O	KOHSOLLP	KOHSOLHP	SCRUBOUT	AIRVENT	LIQOUT	KOHRECIN
Temp (°C)	25.0	25.0	25.0	30.5	30.5	25.0	25.0	25.0	25.0
Pressure (psia)	14.5	14.5	14.5	14.5	29.0	14.5	14.5	14.5	14.5
Vapor Fraction	1	0	0	0	0	0.737	1	0	0
Lbmol/hr	5.4103+06	1.5584+04	2545.8321	1.8581+06	1.8581+06	7.2603+06	5.3475+06	1.9140+06	1.8244+06
Lb/hr	1.5476+08	8.7437+05	4.5864+04	3.9973+07	3.9973+07	1.9471+08	1.5357+08	4.0941+07	3.9053+07
Components (lbmol/hr):									
O_2	1.1087+06	0	0	1.69	1.69	1.1087+06	1.1087+06	1.78	1.69
CO_2	2114	0	0	5.8009-12	5.7906-12	0	0	0	0
N_2	4.1737+06	0	0	3.26	3.26	4.1737+06	4.1737+06	3.43	3.26
Water	1.2576+05	0	2546	1.2438+06	1.2438+06	1.3706+06	6.5135+04	1.3066+06	1.2413+06
KOH	0	0	0	0	0	0	0	0	0
K_2CO_3	0	0	0	0	0	0	0	0	0
$CaCO_3$	0	0	0	0	0	0	0	0	0
CaO	0	0	0	0	0	0	0	0	0
$Ca(OH)_2$	0	0	0	0	0	0	0	0	0
Ca^{2+}	0	0	0	3.6862-05	3.6857-05	4.4137-05	0	4.4338-05	4.3327-05
H_3O^+	0	0	0	0	0	0	0	0	0
$CA(OH)^+$	0	0	0	1.9618-02	1.9617-02	2.1316-02	0	2.1371-02	2.1371-02
K^+	0	0	0	3.1021+05	3.1021+05	3.0705+05	0	3.0704+05	2.9463+05
KOH(S)	0	1.5584+04	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0
$CACO_3(S)$	0	0	0	0	0	0	0	0	0
$K_2CO_3(S)$	0	0	0	0	0	0	0	0	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	0	0	1.7588-03	1.7596-03	0	0	0	0
$HCO3^-$	0	0	0	6.9027-02	6.9036-02	7.8876-02	0	7.8796-02	7.1761-02
OH^-	0	0	0	2.9788+05	2.9788+05	2.9364+05	0	2.9365+05	2.8230+05
CO_3^{2-}	0	0	0	6166	6166	6705	0.00	6695	6166
CISOLID Substream									
Lbmol/hr	0	0	0	0	0	1585	0	1585	0
Lb/hr	0	0	0	0	0	2.1910+05	0	2.1910+05	0
Components (lbmol/hr):									
CaO	0	0	0	0	0	0	0	0	0
KOH(S)	0	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0
$CACO_3(S)$	0	0	0	0	0	0	0	0	0
$K_2CO_3(S)$	0	0	0	0	0	1585	0	1585	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	0	0	0	0	0	0	0	0

Section 12.1.2: Carbonate Transfer via Salt Metathesis

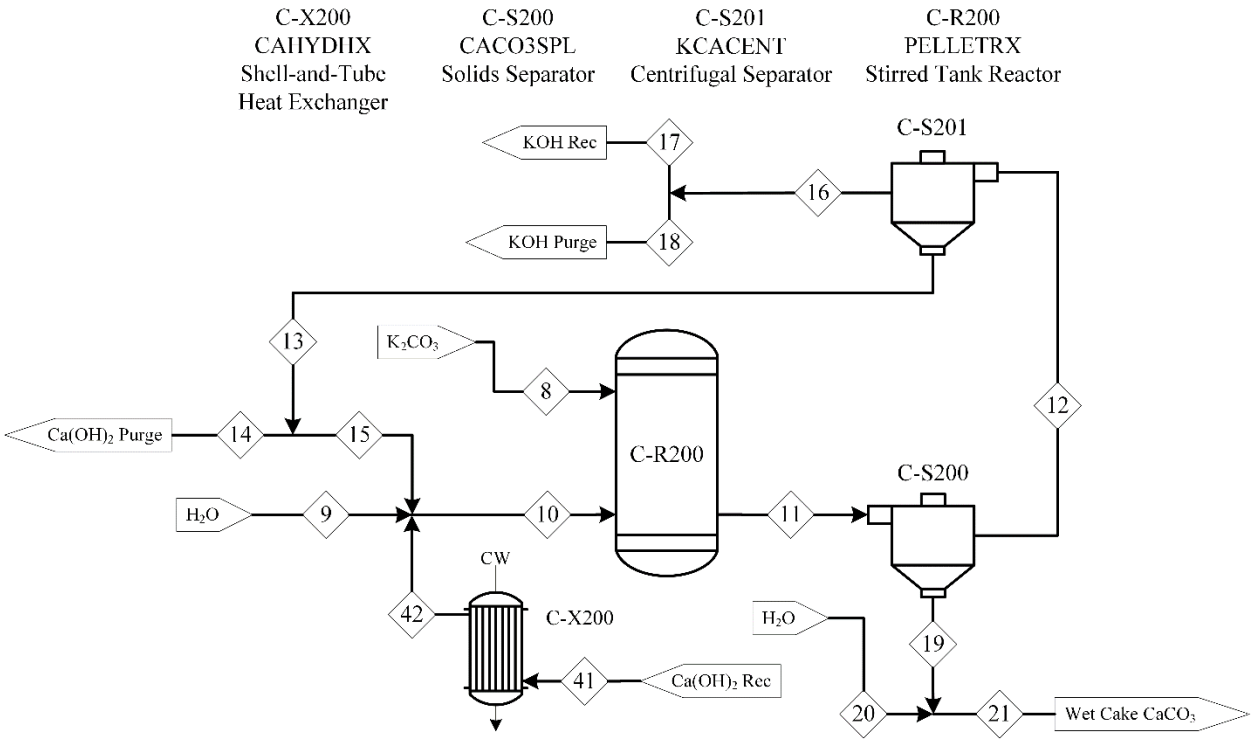


Table 12.1.2: Stream summary table for the salt metathesis reactor process flow diagram. Ion and CISOLID flows (from the ASPEN Electrolyte Wizard) are given.

VISIO Stream ID	8	9	10	11	12	13	13	14
Stream ID	LIQOUT	CAOH2FED	CAOH2IN	PELLTOUT	PELPRODO	CAPRCIN	CAPRCOUT	CARECPRG
Temp (°C)	25.0	25.0	25.4	25.0	25.0	25.0	25.0	25.0
Pressure (psia)	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Vapor Fraction	0	0	0	0	0	0	0	0
Lbmol/hr	1.9140+06	345.5769	1.6403+04	1.9354+06	1.9354+06	1.4975+04	1.4975+04	748.7252
Lb/hr	4.0941+07	2.5605+04	8.1381+05	4.1817+07	4.1817+07	7.0604+05	7.0604+05	3.5302+04
Components (lbmol/hr):								
O_2	1.78	0	8.5047-03	1.79	1.79	8.9523-03	8.9523-03	4.4762-04
CO_2	3.7639-12	0	2.0359-14	3.5460-12	3.5380-12	1.7665-14	1.7665-14	8.8323-16
N_2	3.4293	0	1.6349-02	3.45	3.45	1.72E-02	1.7209-02	8.6046-04
Water	1.3066+06	0	6558	1.3132+06	1.3132+06	6560	6560	328
KOH	0	0	0	0	0	0	0	0
K_2CO_3	0	0	0	0	0	0	0	0
$CaCO_3$	0	0	0	0	0	0	0	0
CaO	0	0	0	0	0	0	0	0
$Ca(OH)_2$	0	0	0	0	0	0	0	0
Ca^{2+}	4.4338-05	0	0	0	0	0	0	0
H_3O^+	2.7438-13	0	0	0	0	0	0	0
$CA(OH)^+$	2.1371-02	0	1.2666-04	2.2626-02	2.2608-02	1.1278-04	1.1278-04	5.6389-06
K^+	3.0704+05	0	1480.5792	3.1169+05	3.1169+05	1558.5045	1558.5045	77.9252
KOH(S)	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0
$CACO_3(S)$	0	0	3824	4033	4047	4025	4025	201
$K_2CO_3(S)$	0	0	0	0	0	0	0	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	345.5769	3091.448	1316.6698	1302.9552	1305.0244	1305.0244	65.2512
$HCO3^-$	7.8796-02	0	3.7493-04	7.6092-02	7.6111-02	3.8018-04	3.8018-04	1.9009-05
OH^-	2.9365+05	0	1418	2.9862+05	2.9865+05	1493	1493	75
CO_3^{2-}	6695	0	31	6537	6523	33	33	1.6341
CISOLID Substream								
Lbmol/hr	1585	0	0	1585	0	0	0	0
Lb/hr	2.1910+05	0	0	1.5867+05	0	0	0	0
Components (lbmol/hr):								
CaO	0	0	0	0	0	0	0	0
KOH(S)	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0
$CACO_3(S)$	0	0	0	1585	0	0	0	0
$K_2CO_3(S)$	1585	0	0	0	0	0	0	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	0	0	0	0	0	0	0

VISIO Stream ID	15	16	17	18	19	20	21	41	42
Stream ID	CARECIN	KOHREC	KOHRECIN	KOHPURGE	CACO3O	WETCAKEW	CO3TOHT	CAOH2WHP	CAHYDC
Temp (°C)	25.0	25.0	25.0	25.0	MISSING	25.0	25.0	55.2	25.0
Pressure (psia)	14.5	14.5	14.5	14.5	MISSING	14.5	14.5	29.0	29.0
Vapor Fraction	0	0	0	0	MISSING	0	0	0	0
Lbmol/hr	1.4226+04	1.9204+06	1.8244+06	9.6021+04	0	463.5634	463.5634	1832.1572	1832.2069
Lb/hr	6.7074+05	4.1109+07	3.9053+07	2.0554+06	1.5867+05	8351.2237	1.6702+05	1.1746+05	1.1746+05
Components (lbmol/hr):									
O_2	8.5047-03	1.78	1.69	8.9184-02	0	0	0	0	0
CO_2	1.6781-14	0	0	0	0	0	0	0	0
N_2	1.6349-02	3.43	3.26	0.171	0	0	0	0	0
Water	6232	1.3066+06	1.2413+06	6.5332+04	0	464	464	326	326
KOH	0	0	0	0	0	0	0	0	0
K_2CO_3	0	0	0	0	0	0	0	0	0
$CaCO_3$	0	0	0	0	0	0	0	0	0
CaO	0	0	0	0	0	0	0	0	0
$Ca(OH)_2$	0	0	0	0	0	0	0	0	0
Ca^{2+}	0	0	0	0	0	0	0	6.1656-02	8.4888-02
H_3O^+	0	0	0	0	0	0	0	0	0
$CA(OH)^+$	1.0714-04	2.2495-02	2.1371-02	1.1248-03	0	0	0	2.3685-02	2.6982-02
K^+	1480.5792	3.1014+05	2.9463+05	1.5507+04	0	0	0	0	0
KOH(S)	0	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0
$CACO_3$(S)	3824	0	0	0	0	0	0	0	0
K_2CO_3(S)	0	0	0	0	0	0	0	0	0
$KHCO_3$(S)	0	0	0	0	0	0	0	0	0
$CAOH_2$(S)	1239.7731	0	0	0	0	0	0	1506	1506
$HCO3^-$	3.6117-04	7.5538-02	7.1761-02	3.7769-03	0	0	0	0	0
OH^-	1418	2.9716+05	2.8230+05	1.4858+04	0	0	0	0.147	0.197
CO_3^{2-}	31	6490	6166	325	0	0	0	0	0
CISOLID Substream									
Lbmol/hr	0	0	0	0	1585	0	1585	0	0
Lb/hr	0	0	0	0	1.5867+05	0	1.5867+05	0	0
Components (lbmol/hr):									
CaO	0	0	0	0	0	0	0	0	0
KOH(S)	0	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0
$CACO_3$(S)	0	0	0	0	1585	0	1585	0	0
K_2CO_3(S)	0	0	0	0	0	0	0	0	0
$KHCO_3$(S)	0	0	0	0	0	0	0	0	0
$CAOH_2$(S)	0	0	0	0	0	0	0	0	0

Section 12.1.3: Calcination of $CaCO_3$

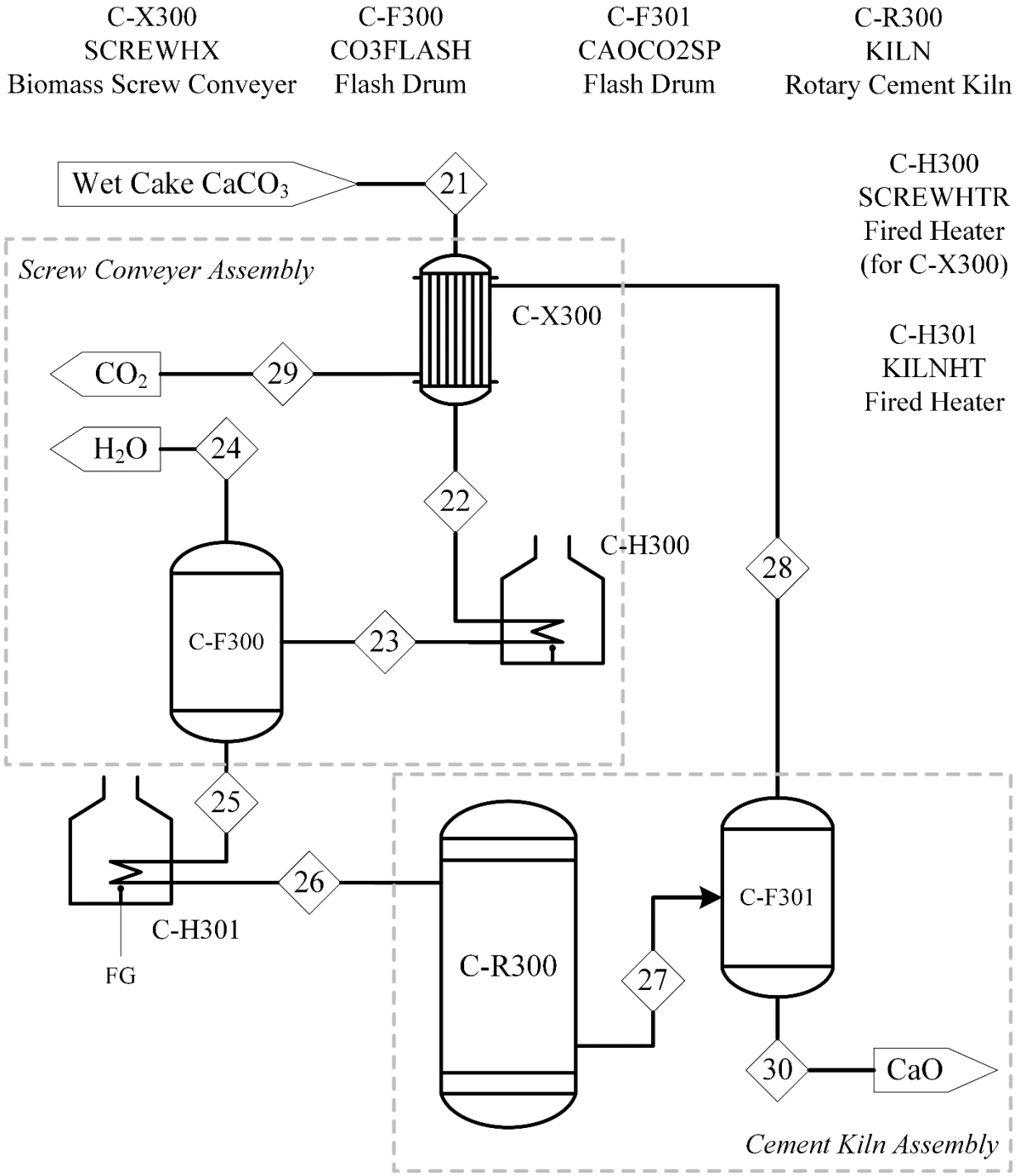


Table 12.1.3: Stream summary table for the calcination process flow diagram. Ion and CISOLID flows (from the ASPEN Electrolyte Wizard) are given.

VISIO Stream ID	21	22	23	24	25	26	27	28	29	30
Stream ID	CO3TOHT	CO3HXHTR	CO3TOFLS	CO3LIQO	CO3HTDRY	KILNFEED	KILNOUTH	CO2HOT	CO2PROD	CAOOUT
Temp (°C)	25.0	269.5	269.5	269.5	MISSING	MISSING	850	850	52.8	MISSING
Pressure (psia)	14.5	14.5	14.5	14.5	14.5	14.5	29.0	29.0	29.0	29.0
Vapor Fraction	0	1	1	1	MISSING	MISSING	1	1	1	MISSING
Lbmol/hr	464	464	464	464	0	0	1585	1585	1585	0
Lb/hr	1.6702+05	1.6702+05	1.6702+05	8351.2237	1.5867+05	0	6.9771+04	6.9771+04	6.9771+04	8.8902+04
Components (lbmol/hr):										
O_2	0	0	0	0	0	0	0	0	0	0
CO_2	0	0	0	0	0	0	1585	1585	1585	0
N_2	0	0	0	0	0	0	0	0	0	0
Water	464	464	464	464	0	0	0	0	0	0
KOH	0	0	0	0	0	0	0	0	0	0
K_2CO_3	0	0	0	0	0	0	0	0	0	0
$CaCO_3$	0	0	0	0	0	0	0	0	0	0
CaO	0	0	0	0	0	0	0	0	0	0
$Ca(OH)_2$	0	0	0	0	0	0	0	0	0	0
Ca^{2+}	0	0	0	0	0	0	0	0	0	0
H_3O^+	0	0	0	0	0	0	0	0	0	0
$CA(OH)^+$	0	0	0	0	0	0	0	0	0	0
K^+	0	0	0	0	0	0	0	0	0	0
KOH(S)	0	0	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0	0
$CACO_3(S)$	0	0	0	0	0	0	0	0	0	0
$K_2CO_3(S)$	0	0	0	0	0	0	0	0	0	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	0	0	0	0	0	0	0	0	0
$HCO3^-$	0	0	0	0	0	0	0	0	0	0
OH^-	0	0	0	0	0	0	0	0	0	0
CO_3^{2-}	0	0	0	0	0	0	0	0	0	0
CISOLID Substream										
Lbmol/hr	1585	1585	1585	0	1585	1585	1585	0	0	1585
Lb/hr	1.5867+05	1.5867+05	1.5867+05	0	1.5867+05	1.5867+05	8.8902+04	0	0	8.8902+04
Components (lbmol/hr):										
CaO	0	0	0	0	0	0	1585	0	0	1585
KOH(S)	0	0	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0	0
$CACO_3(S)$	1585	1585	1585	0	1585	1585	0	0	0	0
$K_2CO_3(S)$	0	0	0	0	0	0	0	0	0	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	0	0	0	0	0	0	0	0	0

Section 12.1.4: Hydrolysis of CaO

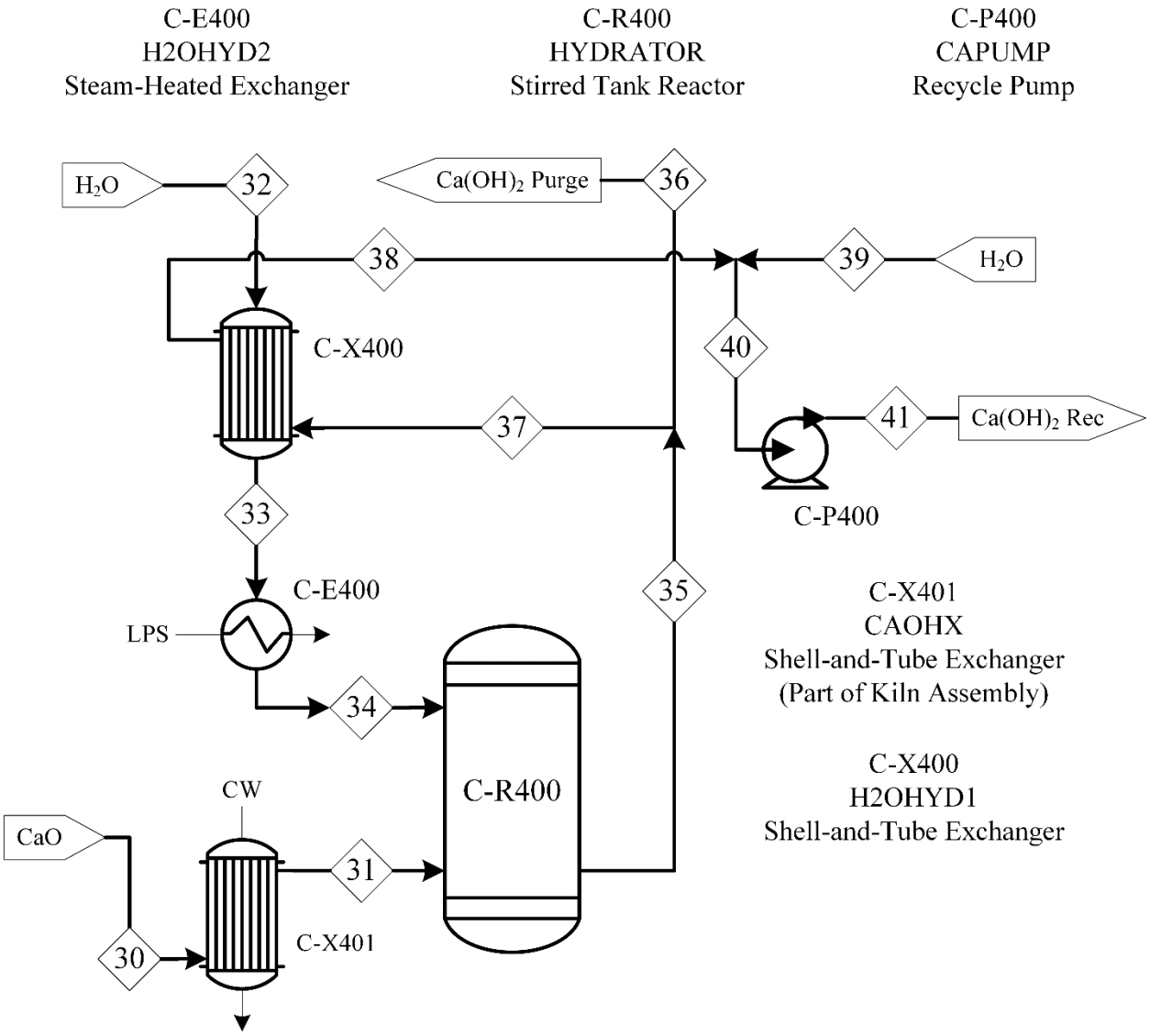


Table 12.1.4: Stream summary table for the CaO hydration reactor process flow diagram. Ion and CISOLID flows (from the ASPEN Electrolyte Wizard) are given.

VISIO Stream ID	30	31	32	33	34	35	36	37	38	39	40	41
Stream ID	CAOOUT	CAOHOT	HYDH2OC	HYDH2OW	HYDH2OH	HYDPRODS	CAOH2PRG	CAOH2H	CAOH2WRM	CARECWTR	CAOH2WLP	CAOH2WHP
Temp (°C)	MISSING	90.0	25.0	62.2	90.0	90.0	90.0	90.0	57.8	25.0	55.1	55.2
Pressure (psia)	29.0	29.0	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	29.0
Vapor Fraction	MISSING	MISSING	0	0	0	0	0	0	0	0	0	0
Lbmol/hr	0	0	1744	1744	1744	1744	87	1657	1657	175	1832	1832
Lb/hr	8.8902+04	8.8902+04	3.1417+04	3.1417+04	3.1417+04	1.2032+05	6015.9444	1.1430+05	1.1430+05	3158.427	1.1746+05	1.1746+05
Components (lbmol/hr):												
O_2	0	0	0	0	0	0	0	0	0	0	0	0
CO_2	0	0	0	0	0	0	0	0	0	0	0	0
N_2	0	0	0	0	0	0	0	0	0	0	0	0
Water	0	0	1744	1744	1744	159	7.93	151	151	175	326	326
KOH	0	0	0	0	0	0	0	0	0	0	0	0
K_2CO_3	0	0	0	0	0	0	0	0	0	0	0	0
$CaCO_3$	0	0	0	0	0	0	0	0	0	0	0	0
CaO	0	0	0	0	0	0	0	0	0	0	0	0
$Ca(OH)_2$	0	0	0	0	0	0	0	0	0	0	0	0
Ca^{2+}	0	0	0	0	0	1.8498-02	9.2489-04	1.7573-02	2.7571-02	0	6.1684-02	6.1656-02
H_3O^+	0	0	3.1488-06	1.0255-05	1.9438-05	9.3958-11	4.6979-12	8.9260-11	1.3616-11	3.1656-07	2.4728-11	2.4799-11
$CA(OH)^+$	0	0	0	0	0	9.6269-03	4.8134-04	9.1456-03	1.0808-02	0	2.3690-02	2.3685-02
K^+	0	0	0	0	0	0	0	0	0	0	0	0
KOH(S)	0	0	0	0	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0	0	0	0
$CACO_3(S)$	0	0	0	0	0	0	0	0	0	0	0	0
$K_2CO_3(S)$	0	0	0	0	0	0	0	0	0	0	0	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	0	0	0	0	1585	79.3	1506	1506	0	1506	1506
$HCO3^-$	0	0	0	0	0	0	0	0	0	0	0	0
OH^-	0	0	3.1488-06	1.0255-05	1.9438-05	4.6623-02	2.3311-03	4.4292-02	6.5950-02	3.1656-07	0.147	0.147
CO_3^{2-}	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID Substream												
Lbmol/hr	1585	1585	0	0	0	0	0	0	0	0	0	0
Lb/hr	8.8902+04	8.8902+04	0	0	0	0	0	0	0	0	0	0
Components (lbmol/hr):												
CaO	1585	1585	0	0	0	0	0	0	0	0	0	0
KOH(S)	0	0	0	0	0	0	0	0	0	0	0	0
KOH*W(S)	0	0	0	0	0	0	0	0	0	0	0	0
KOH:2W(S)	0	0	0	0	0	0	0	0	0	0	0	0
$CACO_3(S)$	0	0	0	0	0	0	0	0	0	0	0	0
$K_2CO_3(S)$	0	0	0	0	0	0	0	0	0	0	0	0
$KHCO_3(S)$	0	0	0	0	0	0	0	0	0	0	0	0
$CAOH_2(S)$	0	0	0	0	0	0	0	0	0	0	0	0

Table 12.1.5: Material balances for the CO_2 capture process. Note that this is on a per-mole basis.

Stream	Inlet/Outlet	Flow Rate (lbmol/hr)
AIRIN	Inlet	5410000
AIRVENT	Outlet	-5347500
CAHYDCWI	Inlet	6355.9
CAHYDCWO	Outlet	-6355.9
CAOH2FED	Inlet	2179.62
CAOH2PRG	Outlet	-87.2
CAOHXCWI	Inlet	49330
CAOHXCWO	Outlet	-49330
CAPRCIN	Inlet	15000
CAPRCOUT	Outlet	-15000
CARECPRG	Outlet	-750.0219
CARECWTR	Inlet	175.32
CO2PROD	Outlet	-1585.35
CO3LIQO	Outlet	-463.56
HYDH2OC	Inlet	1743.88
KOHFEED	Inlet	15580
KOHPURGE	Outlet	-96020
SATAIR	Inlet	7.6401
SATLIQUI	Outlet	-1223.52
SATVAPOR	Outlet	-7.8759
SATWATER	Inlet	1223.7515
SCRUBH2O	Inlet	2545.83
WETCAKEW	Inlet	463.56
--	Net	-13717.9262

**This net balance is still within ASPEN's tolerance, given the large stream flow rates in this process, so the balance does close for CO_2 our capture system.

Section 12.2: Syngas Generation

C-W100 COMP1 Centrifugal Compressor
C-W101 COMP2 Centrifugal Compressor
C-W102 COMP3 Centrifugal Compressor
C-W103 FLUECOMP Centrifugal Compressor
X-W100 COMP1HX Shell-and-Tube Heat Exchanger
X-W101 COMP2HX Shell-and-Tube Heat Exchanger
X-W102 COMP3HX Shell-and-Tube Heat Exchanger
X-W103 ECONOM1 Shell-and-Tube Heat Exchanger
X-W104 ECONOM2 Shell-and-Tube Heat Exchanger
X-W105 WGSFLAHX Shell-and-Tube Heat Exchanger
H-W100 FEEDHEAT Fired Heater
R-W100 HTWGS Packed Bed Reactor
F-W100 FLUFLASH Two-Phase Flash Drum

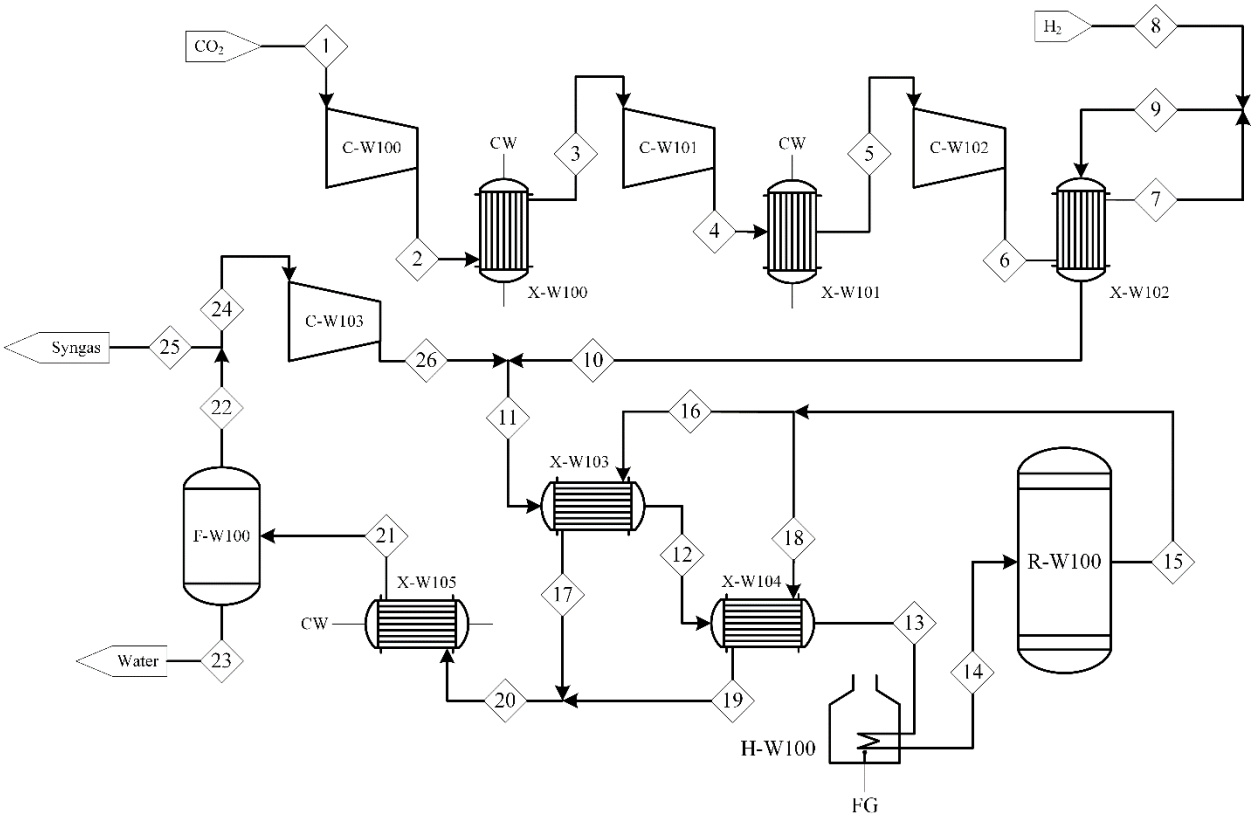


Table 12.2.1: Stream summary table for the water-gas shift process flow diagram.

VISIO Stream ID	1	2	3	4	5	6
Stream ID	CO22BAR	CO26HOT	CO26COLD	CO218HOT	CO218CLD	CO225HOT
Temp (°C)	53	166	49	162	50	87
Pressure (psia)	29	87	84	251	247	363
Vapor Fraction	1	1	1	1	1	1
Lbmol/hr	1,586	1,586	1,586	1,586	1,586	1,586
Lb/hr	69,779	69,779	69,779	69,779	69,779	69,779
Components (lbmol/hr):						
CO_2	1,586	1,586	1,586	1,586	1,586	1,586
CO	0	0	0	0	0	0
H_2	0	0	0	0	0	0
Water	0	0	0	0	0	0
VISIO Stream ID	7	8	9	10	11	12
Stream ID	CO225CLD	H2IN	HPFDMX-3	HPFD3-MX	FEEDCOLD	FEEDWARM
Temp (°C)	60	25	32	38	63	305
Pressure (psia)	363	363	363	363	363	363
Vapor Fraction	1	1	1	1	1	1
Lbmol/hr	1,586	7,928	9,513	9,513	18,141	18,141
Lb/hr	69,779	15,981	85,760	85,760	155,400	155,400
Components (lbmol/hr):						
CO_2	1,586	0	1,586	1,586	2,094	2,094
CO	0	0	0	0	1,068	1,068
H_2	0	7,928	7,928	7,928	14,783	14,783
Water	0	0	0	0	195	195
VISIO Stream ID	13	14	15	16	17	18
Stream ID	FEEDHOT	WGSFEED	WGSOUT	FLUEHOT1	FLUECLD1	FLUEHOT2
Temp (°C)	388	568	500	500	80	500
Pressure (psia)	363	363	363	363	363	363
Vapor Fraction	1	1	1	1	1	1
Lbmol/hr	18,141	18,141	18,141	9,070	9,070	9,070
Lb/hr	155,410	155,410	155,410	77,703	77,703	77,701
Components (lbmol/hr):						
CO_2	2,094	2,094	1,024	512	512	512
CO	1,068	1,068	2,139	1,069	1,069	1,069
H_2	14,784	14,784	13,713	6,857	6,857	6,856
Water	195	195	1,265	633	633	633

VISIO Stream ID	19	20	21	22	23	24
Stream ID	FLUECLD2	FLU2HX	HX2FLASH	FLUEDRY	H2O	FLURC25
Temp (°C)	333	172	58	84	84	84
Pressure (psia)	363	363	358	358	358	358
Vapor Fraction	1	1	1	1	0	1
Lbmol/hr	9,070	18,141	18,141	17,256	885	8,628
Lb/hr	77,701	155,400	155,400	139,290	16,112	69,646
Components (lbmol/hr):						
CO_2	512	1,024	1,024	1,018	6	509
CO	1,069	2,139	2,139	2,137	2	1,068
H_2	6,856	13,713	13,713	13,712	1	6,856
Water	633	1,265	1,265	389	876	195

VISIO Stream ID	25	26
Stream ID	SYNTOFT	FLURC255
Temp (°C)	84	87
Pressure (psia)	358	365
Vapor Fraction	1	1
Lbmol/hr	8,628	8,628
Lb/hr	69,646	69,646
Components (lbmol/hr):		
CO_2	509	509
CO	1,068	1,068
H_2	6,856	6,856
Water	195	195

Table 12.2.2: Material balances for the syngas production system.

	In	Out	Generation	Relative Diff.
Conventional Components (lbmol/hr)				
CO	0	1070	1,070	0
CO_2	1,586	515	-1,070	0
H_2	7,928	6,857	-1,070	0
H_2O	100,035	101,105	1,070	0
TOTAL BALANCE				
Mole (lbmol/hr)	109,548	109,548	0	0
Mass (lb/hr)	1.89E+06	1.89E+06		0
Enthalpy (BTU/hr)	-1.25E+10	-1.25E+10		-0.01

Section 12.3: Fischer-Tropsch (FT) Synthesis

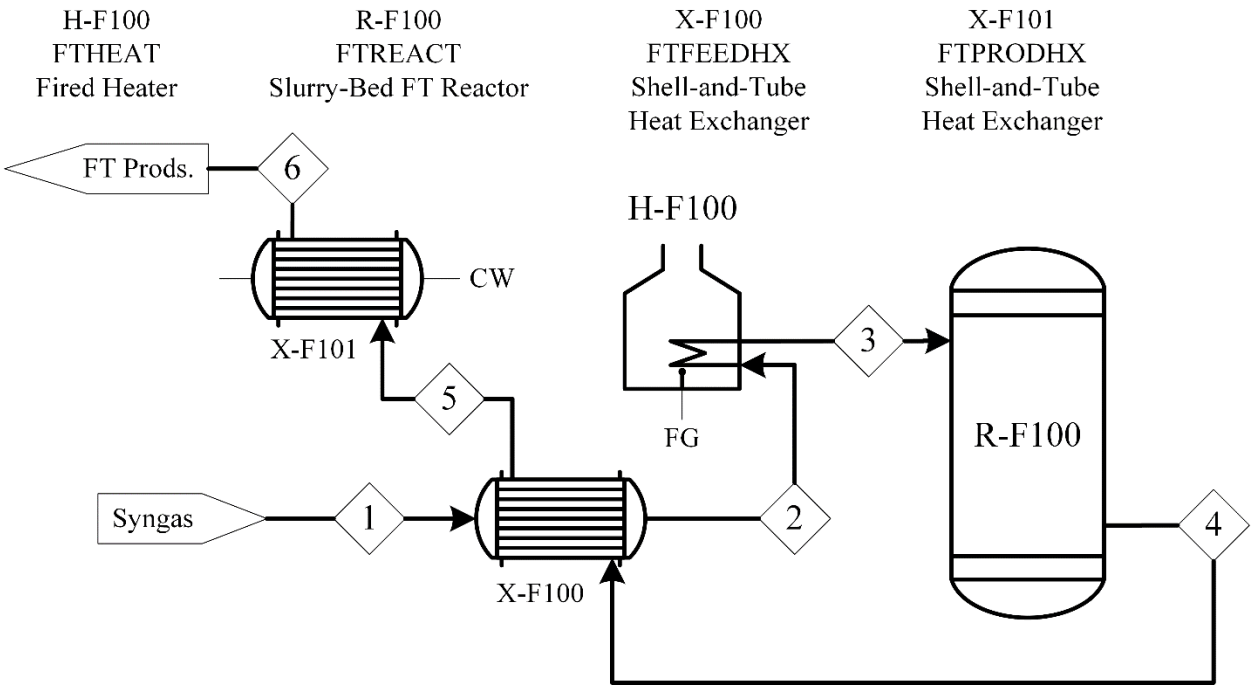


Table 12.3.1: Stream summary table for the Fischer-Tropsch process flow diagram.

VISIO Stream ID	1	2	3	4	5	6
Stream ID	SYNGASC	SYNGASH	FTFEED	FTPRODH	FTPRODW	FTPRODC
Temp (°C)	84.3024	272.22	300	300	143.9394	80
Pressure (psia)	358	358	363	363	363	363
Vapor Fraction	1	1	1	1	1	1
Lbmol/hr	6,716	6,716	6,716	5,054	5,054	5,054
Lb/hr	54,202	54,202	54,202	54,202	54,202	54,202
Components (lbmol/hr):						
CO	832	832	832	1.2	1.2	1.2
CO_2	396	396	396	396	396	396
H_2	5,337	5,337	5,337	3,561	3,561	3,561
H_2O	151	151	151	982	982	982
CH_4	0	0	0	15	15	15
C_2H_6	0	0	0	13	13	13
C_3H_8	0	0	0	11	11	11
C_4H_{10}	0	0	0	10	10	10
C_5H_{12}	0	0	0	8.7	8.7	8.7
C_6H_{14}	0	0	0	7.6	7.6	7.6
C_7H_{16}	0	0	0	6.6	6.6	6.6
C_8H_{18}	0	0	0	5.7	5.7	5.7
C_9H_{20}	0	0	0	5.0	5.0	5.0
$C_{10}H_{22}$	0	0	0	4.3	4.3	4.3
$C_{11}H_{24}$	0	0	0	3.8	3.8	3.8
$C_{12}H_{26}$	0	0	0	3.3	3.3	3.3
$C_{13}H_{28}$	0	0	0	2.9	2.9	2.9
$C_{14}H_{30}$	0	0	0	2.5	2.5	2.5
$C_{15}H_{32}$	0	0	0	2.2	2.2	2.2
$C_{16}H_{34}$	0	0	0	1.9	1.9	1.9
$C_{17}H_{36}$	0	0	0	1.6	1.6	1.6
$C_{18}H_{38}$	0	0	0	1.4	1.4	1.4
$C_{19}H_{40}$	0	0	0	1.2	1.2	1.2
$C_{20}H_{42}$	0	0	0	1.1	1.1	1.1
$C_{21}H_{44}$	0	0	0	1.0	1.0	1.0
$C_{22}H_{46}$	0	0	0	0.79	0.79	0.79
$C_{23}H_{48}$	0	0	0	0.71	0.71	0.71
$C_{24}H_{50}$	0	0	0	0.62	0.62	0.62
$C_{25}H_{52}$	0	0	0	0.54	0.54	0.54
$C_{26}H_{54}$	0	0	0	0.47	0.47	0.47
$C_{27}H_{56}$	0	0	0	0.41	0.41	0.41
$C_{28}H_{58}$	0	0	0	0.35	0.35	0.35
$C_{29}H_{60}$	0	0	0	0.31	0.31	0.31
$C_{30}H_{62}$	0	0	0	0.27	0.27	0.27

Table 12.3.2: Overall material balance for the Fischer-Tropsch fuel synthesis process.

	In	Out	Generation	Relative Diff.
Conventional Components (lbmol/hr)				
CO	832	1.20	-831	0
CO_2	396	396	0	0
H2	5337	3561	-1776	0
H_2O	32497	33328	831	0
CH_4	0	15.2	15.2	0
C_2H_6	0	13.2	13.2	0
C_3H_8	0	11.5	11.5	0
C_4H_{10}	0	10.0	10.0	0
C_5H_{12}	0	8.70	8.70	0
C_6H_{14}	0	7.57	7.57	0
C_7H_{16}	0	6.60	6.60	0
C_8H_{18}	0	5.73	5.73	0
C_9H_{20}	0	4.99	4.99	0
$C_{10}H_{22}$	0	4.34	4.34	0
$C_{11}H_{24}$	0	3.77	3.77	0
$C_{12}H_{26}$	0	3.29	3.29	0
$C_{13}H_{28}$	0	2.85	2.85	0
$C_{14}H_{30}$	0	2.48	2.48	0
$C_{15}H_{32}$	0	2.16	2.16	0
$C_{16}H_{34}$	0	1.87	1.87	0
$C_{17}H_{36}$	0	1.61	1.61	0
$C_{18}H_{38}$	0	1.43	1.43	0
$C_{19}H_{40}$	0	1.23	1.23	0
$C_{20}H_{42}$	0	1.08	1.08	0
$C_{21}H_{44}$	0	0.951	0.951	0
$C_{22}H_{46}$	0	0.794	0.794	0
$C_{23}H_{48}$	0	0.709	0.709	0
$C_{24}H_{50}$	0	0.617	0.617	0
$C_{25}H_{52}$	0	0.536	0.536	0
$C_{26}H_{54}$	0	0.467	0.467	0
$C_{27}H_{56}$	0	0.407	0.407	0
$C_{28}H_{58}$	0	0.354	0.354	0
$C_{29}H_{60}$	0	0.307	0.307	0
$C_{30}H_{62}$	0	0.268	0.268	0
TOTAL BALANCE				
Mole (lbmol/hr)	39062.3	37400.9	-1661.42	0
Mass (lb/hr)	636934	636934		0
Enthalpy (BTU/hr)	-4.08E+09	-4.14E+09		0.014

Section 12.4: Product Separation

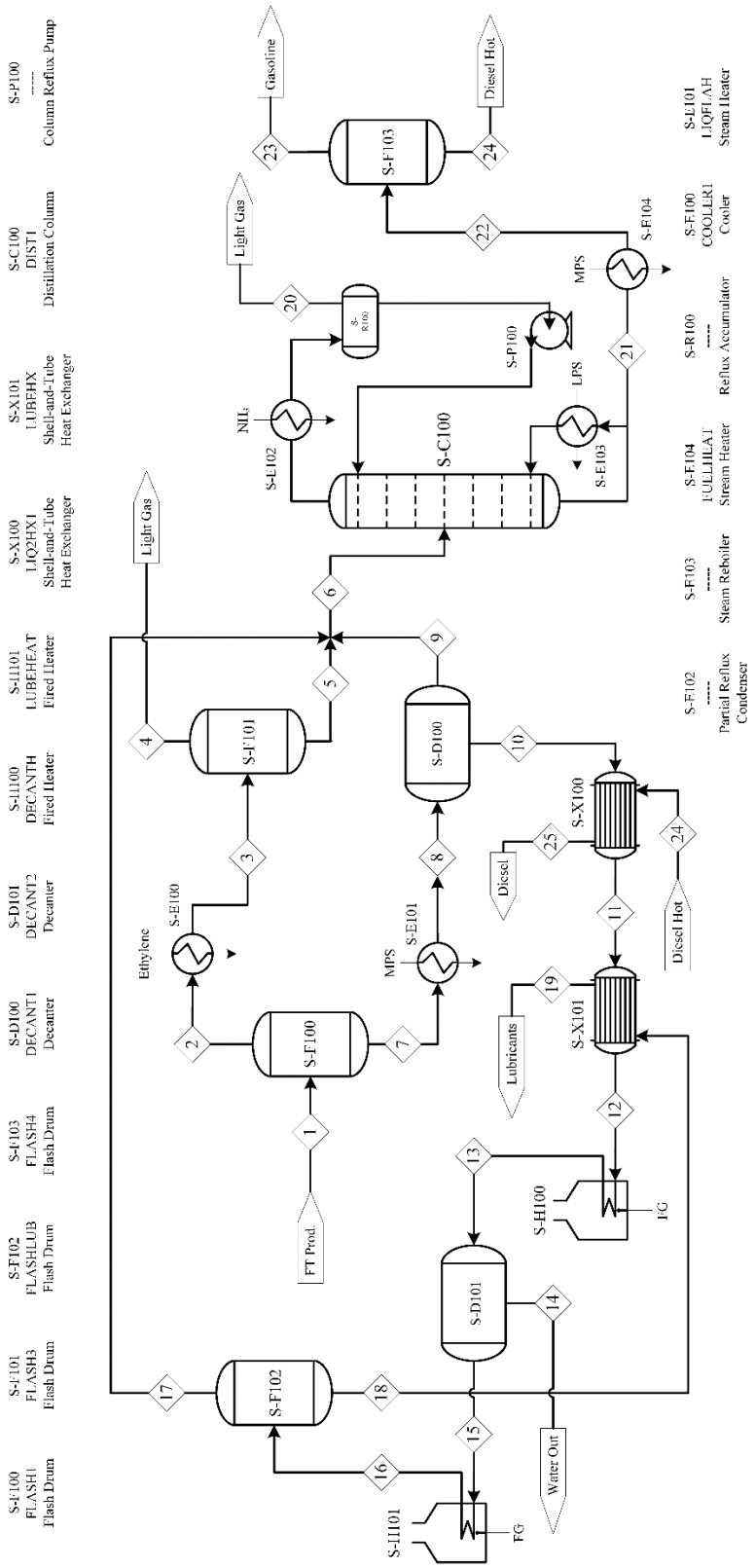


Table 12.4.1: Stream summary table for the separation system process flow diagram.

VISIO Stream ID	1	2	3	4	5	6
Stream ID	FTPROD	FLASHGAS	COLDFLAS	FLASHG2	FLASHLQ3	COL1FEED
Temp (°C)	80	50	-54	-60	-60	40
Pressure (psia)	363	363	363	363	363	363
Vapor Fraction	0.81	1.00	0.98	1.00	0	0.01
Lbmol/hr	5054	4010	4010	3912	98	168
Lb/hr	54,203	26,687	26,687	22,205	4,482	12,660
Components (lbmol/hr):						
CO	1.19	1.18	1.18	1.18	0	0.004
CO_2	396	364	364	322	43.0	62.5
H_2	3,561	3,559	3,559	3,558	0.257	0.335
H_2O	982	19.7	19.7	0.002	19.7	26.2
CH_4	15.2	15.2	15.2	13.0	2.13	2.18
C_2H_6	13.2	13.2	13.2	12.3	0.89	0.937
C_3H_8	11.5	11.3	11.3	3.84	7.43	7.57
C_4H_{10}	10.0	9.52	9.52	1.51	8.01	8.40
C_5H_{12}	8.7101	7.64	7.64	0.15	7.49	8.56
C_6H_{14}	7.57	5.32	5.32	0.02	5.30	7.54
C_7H_{16}	6.6	2.40	2.40	0.00	2.40	6.60
C_8H_{18}	5.73	0.54	0.543	0	0.54	5.73
C_9H_{20}	4.99	0.42	0.424	0	0.42	4.54
$C_{10}H_{22}$	4.34	0.12	0.115	0	0.12	4.34
$C_{11}H_{24}$	3.77	0.05	0.051	0	0.05	3.77
$C_{12}H_{26}$	3.29	0.02	0.016	0	0.02	3.29
$C_{13}H_{28}$	2.85	0.01	5.29E-03	0	0.01	2.85
$C_{14}H_{30}$	2.48	0.00	1.84E-03	0	0.00	2.48
$C_{15}H_{32}$	2.16	0	2.66E-04	0	0.00	2.10
$C_{16}H_{34}$	1.87	0	0	0	0	1.87
$C_{17}H_{36}$	1.61	0	0	0	0	1.48
$C_{18}H_{38}$	1.43	0	0	0	0	1.24
$C_{19}H_{40}$	1.23	0	0	0	0	0.964
$C_{20}H_{42}$	1.08	0	0	0	0	0.737
$C_{21}H_{44}$	0.95	0	0	0	0	0.551
$C_{22}H_{46}$	0.79	0	0	0	0	0.371
$C_{23}H_{48}$	0.71	0	0	0	0	0.275
$C_{24}H_{50}$	0.62	0	0	0	0	0.196
$C_{25}H_{52}$	0.54	0	0	0	0	0.147
$C_{26}H_{54}$	0.47	0	0	0	0	0.101
$C_{27}H_{56}$	0.41	0	0	0	0	0.075
$C_{28}H_{58}$	0.35	0	0	0	0	0.027
$C_{29}H_{60}$	0.31	0	0	0	0	0.044
$C_{30}H_{62}$	0.27	0	0	0	0	0.034

VISIO Stream ID	7	8	9	10	11	12
Stream ID	FLASLIQ2	FLASHWRM	LIQ1COLD	LIQ2	LIQ2WARM	LIQ2WAMR
Temp (°C)	50	120	120	120	123	123
Pressure (psia)	363	363	363	363	363	363
Vapor Fraction	0	0	0	0	0	0
Lbmol/hr	1045	1045	70	974	974	974
Lb/hr	27,516	27,516	8,177	19,339	19,339	19,339
Components (lbmol/hr):						
CO	0.009	0.009	0	8.17E-03	8.17E-03	8.17E-03
CO_2	31.4	31.4	19.5	11.9	11.9	11.9
H_2	2.00	2.00	0.078	1.92	1.92	1.92
H_2O	962	962	6.51	955	955	955
CH_4	0.065	0.07	0.057	8.54E-03	8.54E-03	8.54E-03
C_2H_6	0.052	0.05	0.047	5.27E-03	5.27E-03	5.27E-03
C_3H_8	0.207	0.21	0.146	6.13E-02	6.13E-02	6.13E-02
C_4H_{10}	0.478	0.48	0.389	8.90E-02	8.90E-02	8.90E-02
C_5H_{12}	1.07	1.07	1.07	0	0	0
C_6H_{14}	2.25	2.25	2.23	1.45E-02	1.45E-02	1.45E-02
C_7H_{16}	4.20	4.20	4.20	2.23E-03	0	0
C_8H_{18}	5.19	5.19	5.19	0	0	0
C_9H_{20}	4.57	4.57	4.11	0.4547	0.4547	0.4547
$C_{10}H_{22}$	4.23	4.23	4.22	0	0	0
$C_{11}H_{24}$	3.72	3.72	3.72	0	0	0
$C_{12}H_{26}$	3.27	3.27	3.27	0	0	0
$C_{13}H_{28}$	2.84	2.84	2.84	0	0	0
$C_{14}H_{30}$	2.48	2.48	2.48	0	0	0
$C_{15}H_{32}$	2.16	2.16	2.09	0.065	0.065	0.065
$C_{16}H_{34}$	1.87	1.87	1.87	0	0	0
$C_{17}H_{36}$	1.61	1.61	1.48	0.128	0.128	0.128
$C_{18}H_{38}$	1.43	1.43	1.24	0.189	0.189	0.189
$C_{19}H_{40}$	1.23	1.23	0.964	0.266	0.266	0.266
$C_{20}H_{42}$	1.08	1.08	0.737	0.343	0.343	0.343
$C_{21}H_{44}$	0.950	0.950	0.551	0.399	0.399	0.399
$C_{22}H_{46}$	0.790	0.790	0.371	0.420	0.420	0.420
$C_{23}H_{48}$	0.710	0.710	0.275	0.435	0.435	0.435
$C_{24}H_{50}$	0.620	0.620	0.196	0.424	0.424	0.424
$C_{25}H_{52}$	0.540	0.540	0.147	0.393	0.393	0.393
$C_{26}H_{54}$	0.470	0.470	0.101	0.369	0.369	0.369
$C_{27}H_{56}$	0.410	0.410	0.075	0.335	0.335	0.335
$C_{28}H_{58}$	0.350	0.350	0.027	0.323	0.323	0.323
$C_{29}H_{60}$	0.310	0.310	0.044	0.266	0.266	0.266
$C_{30}H_{62}$	0.270	0.270	0.034	0.236	0.236	0.236

VISIO Stream ID	13	14	15	16	17	17
Stream ID	LIQ2HOT	WATEROUT	HYDROCAR	FEEDLUB	MIDALK	MIDALK2
Temp (°C)	195	195	195	350	350	350
Pressure (psia)	363	363	363	363	363	363
Vapor Fraction	0	0	0	0.10	1.00	0.92
Lbmol/hr	974	974	0.08	0.08	0.01	0.01
Lb/hr	19,339	19,320	19	19	0.41	0.41
Components (lbmol/hr):						
CO	8.17E-03	8.17E-03	0	0	0	0
CO_2	11.9	11.9	1.22E-03	0	9.78E-04	9.78E-04
H_2	1.92	1.92	0	0	1.32E-04	1.32E-04
H_2O	955	955	4.46E-03	0.004	4.17E-03	4.17E-03
CH_4	8.54E-03	8.54E-03	0	0	0	0
C_2H_6	5.27E-03	5.19E-03	0	0	0	0
C_3H_8	6.13E-02	6.12E-02	0	0	0	0
C_4H_{10}	8.90E-02	0.089	0	0	2.40E-04	2.40E-04
C_5H_{12}	0	4.32E-04	0	0	2.28E-04	2.28E-04
C_6H_{14}	1.45E-02	0.01	1.54E-03	0	4.93E-04	4.93E-04
C_7H_{16}	0.00E+00	1.26E-03	0	0	2.08E-04	2.08E-04
C_8H_{18}	0	0	0	0	0	0
C_9H_{20}	0.4547	0.4515	3.23E-03	0	3.98E-04	3.98E-04
$C_{10}H_{22}$	0	5.37E-04	0	0	0	0
$C_{11}H_{24}$	0	0	0	0	0	0
$C_{12}H_{26}$	0	0	0	0	0	0
$C_{13}H_{28}$	0	0	0	0	0	0
$C_{14}H_{30}$	0	0	0	0	0	0
$C_{15}H_{32}$	0.065	5.66E-02	8.38E-03	0	1.60E-04	1.60E-04
$C_{16}H_{34}$	0	0	0	0	0	0
$C_{17}H_{36}$	0.128	0.118	1.03E-02	0.010	1.11E-04	1.11E-04
$C_{18}H_{38}$	0.189	0.178	1.08E-02	0.011	0	0
$C_{19}H_{40}$	0.266	0.256	1.00E-02	0.010	0	0
$C_{20}H_{42}$	0.343	0.335	8.07E-03	0.008	0	0
$C_{21}H_{44}$	0.399	0.393	6.06E-03	0.006	0	0
$C_{22}H_{46}$	0.420	0.416	0	0	0	0
$C_{23}H_{48}$	0.435	0.433	0	0	0	0
$C_{24}H_{50}$	0.424	0.422	0	0	0	0
$C_{25}H_{52}$	0.393	0.392	0	0	0	0
$C_{26}H_{54}$	0.369	0.369	0	0	0	0
$C_{27}H_{56}$	0.335	0.335	0	0	0	0
$C_{28}H_{58}$	0.323	0.323	0	0	0	0
$C_{29}H_{60}$	0.266	0.266	0	0	0	0
$C_{30}H_{62}$	0.236	0.236	0	0	0	0

VISIO Stream ID	18	19	20	21	22	23
Stream ID	LUBE	LUBEOUT	GASES	FLASHFE	FUELFLAS	GASOLINE
Temp (°C)	350	151	-28	63	170	170
Pressure (psia)	363	363	15	15	15	15
Vapor Fraction	0	0	1.00	0	0.77	1.00
Lbmol/hr	0.07	0.07	84	84	84	64
Lb/hr	18	18	3,782	8,878	8,878	4,831
Components (lbmol/hr):						
CO	0	0	3.65E-03	0	0	0
CO_2	0	0	62.5	0	0	0
H_2	0	0	0.335	0	0	0
H_2O	0	0	0.072	26.1	26.1	26.1
CH_4	0	0	2.18	0	0	0
C_2H_6	0	0	0.937	0	0	0
C_3H_8	0	0	7.57	0	0	0
C_4H_{10}	0	0	8.40	0.005	5.01E-03	4.98E-03
C_5H_{12}	0	0	1.99	6.57	6.57	6.47
C_6H_{14}	0	0	0	7.54	7.54	7.29
C_7H_{16}	0	0	0	6.60	6.60	6.20
C_8H_{18}	0	0	0	5.73	5.73	5.18
C_9H_{20}	0	0	0	4.54	4.54	3.78
$C_{10}H_{22}$	0	0	0	4.34	4.34	3.17
$C_{11}H_{24}$	0	0	0	3.77	3.77	2.36
$C_{12}H_{26}$	0	0	0	3.29	3.29	1.60
$C_{13}H_{28}$	0	0	0	2.85	2.85	0.999
$C_{14}H_{30}$	0	0	0	2.48	2.48	0.659
$C_{15}H_{32}$	8.22E-03	8.22E-03	0	2.10	2.10	0.372
$C_{16}H_{34}$	0	0	0	1.87	1.87	0.174
$C_{17}H_{36}$	0.010	0.010	0	1.48	1.48	0.086
$C_{18}H_{38}$	0.011	0.011	0	1.24	1.24	0.046
$C_{19}H_{40}$	9.93E-03	9.93E-03	0	0.964	0.964	0.021
$C_{20}H_{42}$	8.03E-03	8.03E-03	0	0.737	0.737	9.41E-03
$C_{21}H_{44}$	6.04E-03	6.04E-03	0	0.551	0.551	4.19E-03
$C_{22}H_{46}$	0.00E+00	0	0	0.371	0.371	1.76E-03
$C_{23}H_{48}$	0.00E+00	0	0	0.275	0.275	7.50E-04
$C_{24}H_{50}$	0	0	0	0.196	0.196	3.23E-04
$C_{25}H_{52}$	0	0	0	0.147	0.147	1.45E-04
$C_{26}H_{54}$	0	0	0	0.101	0.101	0
$C_{27}H_{56}$	0	0	0	0.075	0.075	0
$C_{28}H_{58}$	0	0	0	0.027	0.027	0
$C_{29}H_{60}$	0	0	0	0.044	0.044	0
$C_{30}H_{62}$	0	0	0	0.034	0.034	0

VISIO Stream ID	24	24	25
Stream ID	DIESELHO	DIESEL	DIESELCO
Temp (°C)	170	170	148
Pressure (psia)	15	15	15
Vapor Fraction	0	0	0
Lbmol/hr	20	20	20
Lb/hr	4,047	4,047	4,047
Components (lbmol/hr):			
CO	0	0	0
CO_2	0	0	0
H_2	0	0	0
H_2O	0.034	0.034	0.034
CH_4	0	0	0
C_2H_6	0	0	0
C_3H_8	0	0	0
C_4H_{10}	0	0	0
C_5H_{12}	0.095	0.095	0.095
C_6H_{14}	0.245	0.245	0.245
C_7H_{16}	0.401	0.401	0.401
C_8H_{18}	0.547	0.547	0.547
C_9H_{20}	0.759	0.759	0.759
$C_{10}H_{22}$	1.17	1.17	1.17
$C_{11}H_{24}$	1.40	1.40	1.40
$C_{12}H_{26}$	1.69	1.69	1.69
$C_{13}H_{28}$	1.85	1.85	1.85
$C_{14}H_{30}$	1.82	1.82	1.82
$C_{15}H_{32}$	1.72	1.72	1.72
$C_{16}H_{34}$	1.70	1.70	1.70
$C_{17}H_{36}$	1.40	1.40	1.40
$C_{18}H_{38}$	1.19	1.19	1.19
$C_{19}H_{40}$	0.944	0.944	0.944
$C_{20}H_{42}$	0.727	0.727	0.727
$C_{21}H_{44}$	0.547	0.547	0.547
$C_{22}H_{46}$	0.369	0.369	0.369
$C_{23}H_{48}$	0.274	0.274	0.274
$C_{24}H_{50}$	0.196	0.196	0.196
$C_{25}H_{52}$	0.147	0.147	0.147
$C_{26}H_{54}$	0.101	0.101	0.101
$C_{27}H_{56}$	0.075	0.075	0.075
$C_{28}H_{58}$	0.027	0.027	0.027
$C_{29}H_{60}$	0.044	0.044	0.044
$C_{30}H_{62}$	0.034	0.034	0.034

Table 12.4.2: Material balance for the product separation system.

Streams	Inlet/Outlet	Mole Flow (lbmol/hr)
DIESELCO	Outlet	-19.51
FLASHG2	Outlet	-3911.98
FTPROD	Inlet	5054.39
GASES	Outlet	-84
GASOLINE	Outlet	-64.49
LUBEOUT	Outlet	-0.0717
WATEROUT	Outlet	-974.33
--	Net	0.0083

Section 13

Process Description

Process Description

The overall process for the conversion of atmospheric CO_2 and gaseous hydrogen into liquid hydrocarbons is described in order in each of the sections below. All components of this process, with the exception of the hydrogen production facility, have been modelled using the ASPEN Plus V10 simulation software.

Section 13.1: Hydrogen Production

To generate a pure stream of hydrogen for use in the reforming of CO_2 and later in the Fischer-Tropsch hydrocarbon synthesis process, water is split via electrolysis in a bank of electrolyzers. The hydrogen is produced at a pressure of 363-435 bar. The hydrogen is sent along to the syngas generation facility (**Section 13.3**) and to the Fischer-Tropsch reactor (**Section 13.4**).

Section 13.2: Carbon Dioxide Capture & Purification

The technology used in this model for carbon capture is based on the technology presented in patents filed by Carbon Engineering. A basic solution is used to scrub the CO_2 from the air, and the gas is stored as a solid in the form of metal carbonates. The carbonate is shuttled between metals before being converted back into pure, gaseous form through decarboxylation. Within this larger capture operation, there are four distinct subprocesses: the initial CO_2 scrubbing, transfer of the carbonate via salt metathesis, calcination (decarboxylation) of the carbonate to recover the CO_2, and finally hydrolysis of the calcination products to recover one of the mass-transfer agents. Each of these subprocesses are discussed in the sections below.

Section 13.2.1: CO_2 Scrubbing

The initial scrubbing section occurs in an outdoor facility under ambient conditions, the incoming air stream containing 400 ppm CO_2 contacts a concentrated (~11 molar) aqueous KOH scrubbing solution, which is comprised of some fresh KOH and some recycled KOH from downstream in the process. Our design and operating principles for this unit are based on Carbon Engineering's patent information for their carbon capture system, which houses separate, modular capture units in a steel superstructure, as seen in the **Figure 2**.[25]

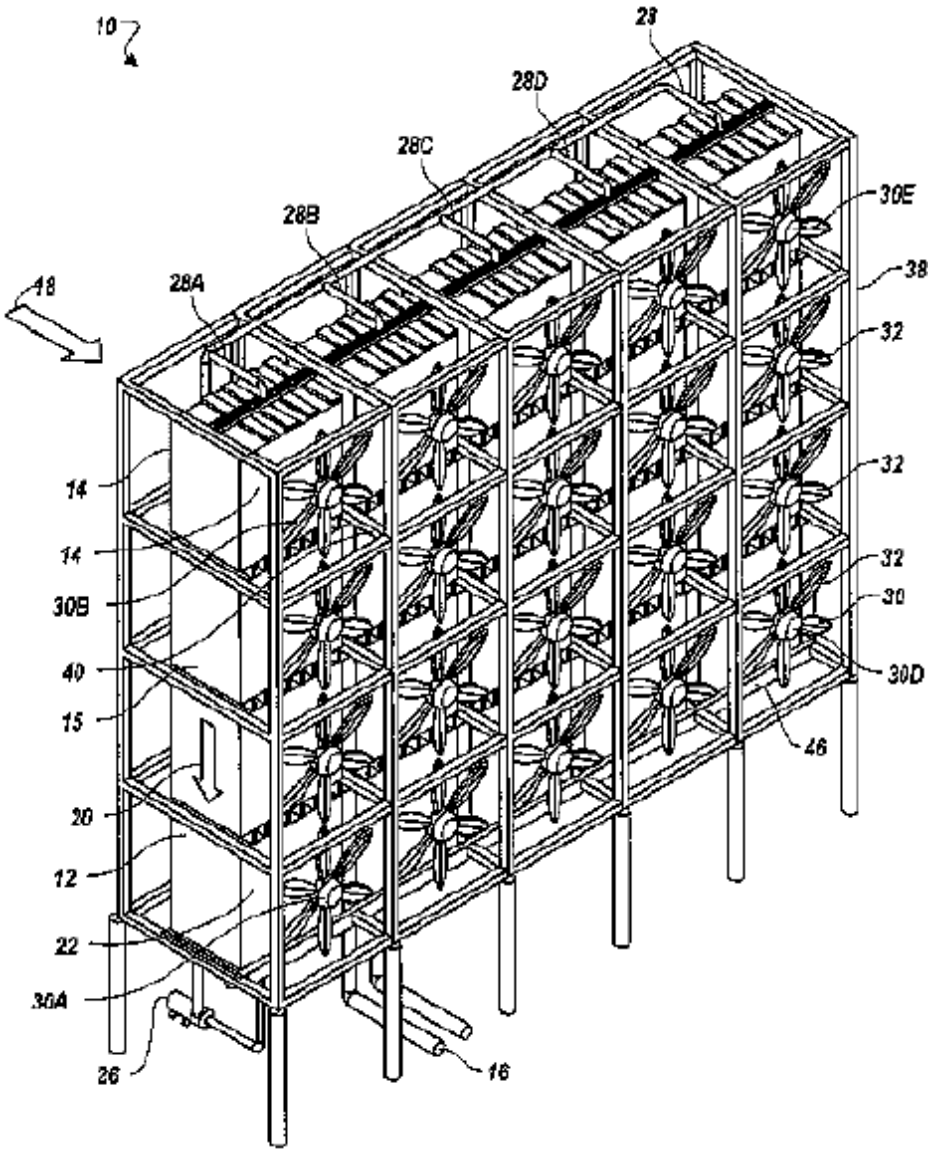


Figure 2: Image of Carbon Engineering's fan bank for their CO_2 capture system.[25]

In a cross-flow mechanism, the KOH contacting solution flows downward by gravity as the air is pulled laterally through the capture mechanism by the fans. The patent information describes a series of pulse intervals for the introduction of the scrubbing solution, rather than a continuous flow. The OH^- ions in the solution preferentially interact with the CO_2 via standard acid-base chemistry, and potassium carbonate and some

bicarbonate (K_2CO_3 and $KHCO_3$, respectively) are formed. The contact solution falls down into a basin, where it collected at the bottom of each scrubbing structure to be piped to a separate processing facility.

Section 13.2.2: Carbonate Transfer via Salt Metathesis

The potassium carbonate solution is then reacted with calcium carbonate ($Ca(OH)_2$) to transfer the carbonate ion from the potassium to the calcium and generate calcium carbonate ($CaCO_3$).[25] This step exploits the difference in solubility between the potassium and calcium carbonate species. $CaCO_3$ is considerably less soluble in water at these temperatures, so the formation of this species drives the reactivity forward via Le Chatelier's principle. Precipitation of $CaCO_3$ helps us achieve greater reactivity of the incoming K_2CO_3 than would perhaps normally be achieved with equilibrium alone. A solid splitter divides this crystallizer effluent into a liquid stream and a solid stream, the latter of which is mixed with fresh process water such that the resulting stream is defined to have 5% liquid by mass to facilitate transport. Normally, the split fraction in the solid splitter could be modified to give the desired liquid mass fraction, but the presence of ions in the stream cause flashing errors in later sections of the ASPEN flowsheet. Thus, we used new process water to set this mass fraction.

The liquid stream is diverted to a recycling unit, where any excess $Ca(OH)_2$ solid is separated from the liquid by means of a centrifugal separator. Solid $Ca(OH)_2$ is diverted back to a mixer, where it joins the fresh $Ca(OH)_2$ entering from outside the process to be mixed with water before entering the RSTOIC reactor to perform the metathesis reaction.

The solid wet cake $CaCO_3$ is sent on to the calcination process for high-temperature recovery of the pure CO_2 stream.

Section 13.2.3: Calcination of $CaCO_3$

This step is modelling the thermal degradation of the $CaCO_3$ solid into CaO by means of CO_2 evolution. The $CaCO_3$ wet cake with 5% liquid by mass nters a shell-and-tube heat exchanger, then a heater, and finally a flash block. These three blocks together are meant to represent and perform the same function as a screw extruder (see **Section 12.1.3** for the flowsheet for this subprocess). Screw conveyors are typically used by biomass processing industries to both move and dry the biomass to be incinerated for energy. Similar technologies are also used by the polymer processing industry for heating of the plastic pellets into a melt prior to injection molding. In all cases, the technology behaves the same: the solid to be heated is fed into a hopper. A screw then carries the solid cake down a tube, compressing it against the tube walls as it goes along. The friction in this process heats the solid. Depending on the application, this tube can either be heated or cooled by an indirect heat transfer through a jacket surrounding the screw and tube complex. In the case of polymeric materials, the solid is then melted and sent on, and the tube is cooled with cooling water to prevent overheating and degradation of the plastic. In our application, we are using the heat generated by this extruder, coupled with indirect heating via the surrounding jacket, to dry the wet cake up to at least 250°C into a granular form before calcination. Removing the excess liquid in this way prevents contamination of the CO_2 stream generated during calcination, as well as decrease the thermal capacity of the stream, leading to more efficient firing of the $CaCO_3$. In terms of ASPEN's processes,

the heat exchanger brings the wet cake up to 100°C, then a heater vaporizes the water and takes the now dry $CaCO_3$ and water vapor streams up to 270°C. Flashing this stream at the same temperature with no effective pressure drop removes the water vapour and leaves us the desired dry $CaCO_3$ stream.

The dried $CaCO_3$ then enters a tubular kiln for calcination. This is modelled after the cement kilns used in industry due to the similarity in the process requirements and functions as a gas-fired tube lined with refractory brick. The kiln is fired at 800-900°C (850°C in our process) with low-boiling hydrocarbon gases recovered from later in our processing facility. The $CaCO_3$ enters the top of the tubular, rotating, angled kiln, so as the firing tube rotates, the $CaCO_3$ is conveyed down the length of the kiln, reacting along the way and generating our stream of CO_2. At the end, the CaO product exits the tube to be conveyed to the hydrolysis unit downstream. This cement kiln will be sealed with mechanical seals at both ends, which will allow a small pressure increase (which we assume to be about 1 bar) to form within the kiln as the gas is evolved. The CO_2 mixes with the firing gas exhaust to generate the effluent gas stream. The contribution of any exhaust gases from the firing of the kiln are not taken into account in our material balances due to the limitations of the ASPEN modelling. Our CO_2 effluent stream is routed through a process-to-process heat exchanger before being sent to the syngas generation facility, which cools it from the 850°C to about 53°C as it heats the wet cake up to 100°C.

Section 13.2.4: Hydrolysis of CaO

The last step in the carbon capture process is the recycling of the $Ca(OH)_2$ back into the salt metathesis reactor described in **Section 13.2.2**. The calcined CaO stream from the

kiln is conveyed to a tank reactor, where a 10% molar excess of process water is mixed with the dried CaO pellets. This reaction rehydrates the anhydrous CaO back into $Ca(OH)_2$ at 90°C, which is then conveyed back. The stream runs through a heat exchanger to be cooled back down to 25°C with cooling water, then into a manifold to be mixed with the fresh $Ca(OH)_2$ and reintroduced into the system.

Section 13.3: Syngas Generation

The feed to our Fischer-Tropsch production unit is syngas ($CO+H_2$). The H_2 is generated by the electrolysis facility, but the CO must be generated via reforming of CO_2. This is accomplished via the reverse water-gas shift reaction (rWGS), which is given as *Equation (1)*. Water-gas shift on an industrial scale is typically used to hydrogen production from methane when combined with the steam methane reforming reaction (SMR). Thus, the traditional WGS reaction (the reverse of *Equation (1)*) is used to react CO in the feed stream with water, first at low temperature, then at a high temperature, to remove as much CO as possible and purify the hydrogen stream.

$$H_2\ (g) + CO_2\ (g) \rightleftharpoons CO\ (g) + H_2O\ (g) \qquad (1)$$

For our purposes, we wish to run this reaction in the opposite direction (hence *reverse* water-gas shift in our case) and generate CO from an incoming CO_2 stream. Given the thermodynamic data for this process, the forward reaction is exothermic, and the reverse direction is endothermic, leading us to pay an energetic cost to reform our CO_2 into CO. To overcome this barrier, we use two methods to drive the reaction more toward completion. First, we must run our rWGS reactor at high temperature, and second, we must remove some water – an unwanted

byproduct – before recycling part of the reactor effluent back in. Each of these will measurably increase the conversion of our pure CO_2 stream to CO.

The downstream Fischer-Tropsch reactor operates at the high pressure of 25-26 bar, and our electrolysis system generates hydrogen at high pressure (25-30 bar, 363-435 psia), so we run the syngas generation unit at this pressure to avoid wasting the hydrogen pressure. The 1:1 stoichiometry of the reaction indicates that pressure will not affect the equilibrium. The incident CO_2 stream from the calcinator is first compressed from its initial pressure of 29 to 363 psia in a series of three compressors. The first two compressors operate on a 3:1 compression ratio, compressing from 29 to 87 psia, then from 87 to 261 psia. Due to the temperature increase during this compression, interstage cooling is introduced after each compression stage via shell-and-tube heat exchangers. The first two exchangers are supplied with cooling water on the tube side. The compressed gas exits the hot side of the exchanger at 50°C. Each of these compressors are modelled as centrifugal compressors and operate at a polytropic efficiency of 75%, based on a conservative estimate of the standard industry efficiency range for centrifugal compression units.[33]

The high-pressure CO_2 is now mixed with high-pressure hydrogen stream coming from the electrolysis units. This feed stream is routed through the third compression heat exchanger in a process-to-process economizer. The heated feed stream is mixed with recycled reactor effluent, and this feed enters into a series of two economizers for internal heat exchange. The warmed feed enters a final heater to reach 577°C before being fed into the reactor. The reactor is modelled as an equilibrium reactor and run adiabatically with the effluent exiting at 500°C, which are specifications in line with industrial practices.[34] At this temperature, we achieve an equilibrium constant (albeit for the forward reaction) of 0.5, just shy of a proper driving force in our

direction.[35] The temperature dependence of the equilibrium K_{eq} is shown in **Figure 3**. Regardless, we still get reasonable conversions of the CO_2 to CO, on the order of 61% with a 50% recycle.

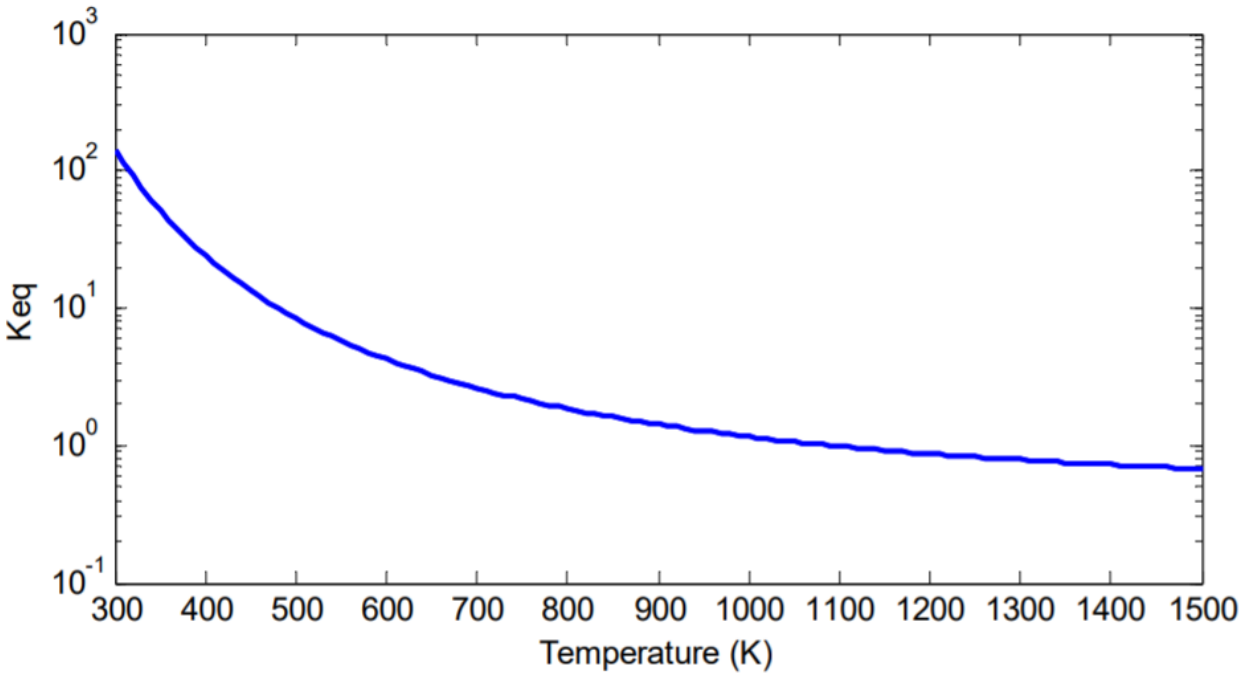


Figure 3: Temperature dependence of the equilibrium constant K_{eq} for the forward water-gas shift reaction.[35]

Water-gas shift reactors are typically run in industry as an adiabatic packed bed reactor, with the catalyst supported on a packing in the reactor vessel. Raising the temperature would increase conversion, but a temperature too high above the standard industrial practice could lead to deactivation of the catalyst. Thus, we have chosen the upper limit of industrial WGS temperatures for this reactor. Additionally, increasing the recycle ratio would also increase conversion, but this is offset by the amount of syngas needed for the downstream Fischer-Tropsch synthesis. A recycle ratio of 50% balances these two variables.

The effluent stream is split into two, and each is run through the hot (shell) side of one of the economizer heat exchangers used to preheat the feed. The now-cooled flue is cooled with cooling water before being flashed at 90°C and 25 bar (363 psia) to reach a water content of 5% by mass. The water is discarded, and the dry gas stream is split in half. One half of this stream is recycled and mixed with the new CO_2 and H_2 gas to further increase conversion of the CO_2, and the other half is sent on to the Fischer-Tropsch unit for polymerization into hydrocarbon products.

Section 13.4: Fischer-Tropsch (FT) Synthesis

It is prudent to begin with a brief discussion of the theory behind the Fischer-Tropsch reaction. Discovered in the 1920s by German chemists Franz Fischer and Hans Tropsch, the eponymous process is a polymerization reaction between CO and hydrogen gas to produce alkanes and water. The polymerization reaction can be best understood by considering the conversions as reactions in series: all CO is first converted to methane, after which a probability distribution governs the fraction of methane molecules that combine to produce ethane. Likewise, some (albeit fewer) combine to form propane, and so on. The mechanics of this polymerization are governed by the Anderson-Schulz-Flory (ASF) Distribution, which is a mathematical equation that dictates the weight fraction of the carbon atom in question. The equation is dependent on a factor, alpha, which in turn is dependent on several properties, namely the chosen catalyst and the temperature and pressure of the reactor. One of the typical Fischer-Tropsch catalysts is iron-based, which tends to shift the distribution to lower-weight alkanes and alkenes. Another, cobalt, favors medium weight alkanes with high selectivity, which is ideal for our fuel plant. This plant makes use of a 20% cobalt on SBA-15, a type of porous silicon, which tends to have an alpha value of around 0.87.[36] Graphs of the ASF Distribution at various values of alpha are included in **Figure 4**.

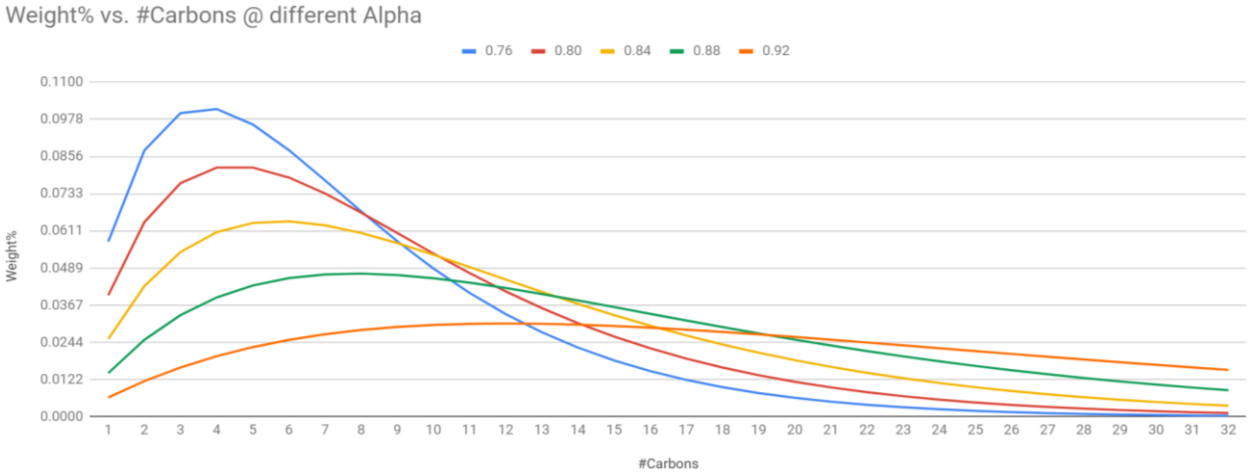


Figure 4: Alkane weight per cent versus carbon number for various alpha values. Our desired distribution is approximately the green line (alpha = 0.88).

In the AIR TO FUELS™ process, syngas produced by the reverse water-gas shift reaction is mixed with a fresh stream of hydrogen gas in order to achieve the ideal ratio of hydrogen feed to CO feed of 2.1 to 1. However, to aid in reforming, a five-fold excess of hydrogen is mixed with the CO_2 entering the reforming stage. The syngas output enters this portion of the AIR TO FUELS™ process at approximately 90°C and 363 psi bar. This feed is then fed to a process-to-process heat exchanger to be heated to essentially the standard conditions of a Fischer-Tropsch reactor as recorded by Sasol, the South African company that has been using this technology since the 1950s.[37][38] The heat exchanger makes use of the reactor effluent as the hot fluid and is able to heat the feed to 272°C. Sasol standard reactors, such as the one included in this process, are operated at 350°C and 363 psia, thus the feed is then heated with a standard heater to the necessary temperature. This high pressure and temperature, combined with the standard residence time of 4.7 seconds allow for the assumption of 100% conversion to be made. Thus, no recycle stream has been included in the process. Instead, the product stream enters two successive heat exchangers.

The first of these exchangers is the process-to-process exchanger mentioned earlier that heats the feed to near reaction conditions and cools the product to nearly separation conditions. The second exchanger is a cooling water exchanger that cools the product to 80°C, which is the required temperature for the first separation step. It is important to note that this entire portion of the process occurs at approximately 363 psia as recorded in literature. This high pressure will also aid in the separation process immediately following.

Section 13.5: Product Separation

Section 13.5.1: Removal of Inert Gas

The Fischer-Tropsch product contains vast amounts of unreacted hydrogen and inert carbon dioxide. Both of these gases, alongside the trace amount of remaining carbon monoxide and the water product must be removed before distillation is attempted. This is due to the large amount of azeotropes that exist between the alkane product and these byproducts and inerts (for example, carbon dioxide and hexane show and azeotrope that interferes with normal distillation).[39] To undergo this purification of product, it is first fed to a flash drum at 80°C and 25 bar to create a gas stream and a liquid stream. The gas stream will be considered first. The stream is cooled to -54°C with a heat exchanger making use of ethylene as a refrigerant, then flashed at that temperature and 25 bar. This flash drum is able to eliminate nearly all of the hydrogen and carbon dioxide, which exit in the vapor phase and can be reused for heat earlier in the process. The liquid stream is then fed to a mixer where it joins the purified liquid stream that exited from the original flash drum.

Section 13.5.2: Water Removal

The liquid stream from the first flash drum will be considered in this subsection. Due to Aspen's lack of data regarding interactions between water and the heavier alkanes, it has difficulty in recognizing their existence in separate liquid phases. As such, it is necessary to decant this liquid stream twice in order to achieve high levels of product purity. The first decanter operates at 120°C and 363 psia and is able to separate the liquid stream into a water and lubricant rich phase and a lighter alkane phase. The second decanter operates at 27°C and 363 psia. This second decanter removes a stream consisting almost entirely of water and a stream containing only products. Again, it is important to note that this step is necessary to avoid the azeotropes that interfere when alkanes are distilled in the presence of water.

Section 13.5.3: Heavy Alkane Removal

This hydrocarbon rich liquid is then flashed at 350°C and 363 psi in order to remove a stream of high value lubricants that are not used in fuel refining but can be sold as valuable products in their own right. The middle alkanes also present in that stream continue on to the mixer mentioned above, where they join the hydrocarbon rich liquid from the first decanter and the purified gaseous stream from the original flash drum.

Section 13.5.4: Distillation and Final Flash

Following this, the product is fed to a single distillation column intended to remove any excess gases that are only useful as a source of energy (the light alkanes, any excess carbon dioxide, etc.). To properly achieve the desired separation, the column must operate

at a fairly low temperature and make use an ammonia coolant. Though this may appear to be unnecessary, the split achieved is precisely as desired. The bottoms of the column is then heated to 170°C and then flashed at that temperature and 15 psia of pressure in order to separate the diesel and gasoline fuel streams, which are then used as sources of heat integration for the separations process. Results for these streams included in the appendix indicate that the process is able to remove nearly all of the possible pollutants from the fuel streams effectively, as well as creating two distinct cuts of fuel to be sold to refiners.

Section 14

Energy Balance & Utility Requirements

Energy Balance & Utility Requirements

The operation of the AIR TO FUELS™ plant requires significant amounts of several different utilities, though electricity is not required due to the installation of solar panels to provide for the power requirements for the process (this essentially concentrates the cost of electricity into the capital cost as opposed to regular payments). For this plant, the following utilities are required: cooling water, chilled water, low and medium pressure steam, fuel gas, ammonia, and ethylene. Though common industrial utilities are extremely cheap, the cost is drastically increased due to the sheer amount required. The AIR TO FUELS™ plant moves massive amounts of material in order to produce the requisite 2000 bbl/day of fuel and operates at high pressures and great fluctuations in temperature to accomplish this task. As an example, the compression of carbon dioxide gas from essentially atmospheric pressure to 25 bar also heats up the gas, therefore this must occur in a three-fold compression with cooling water heat exchangers after the first two steps. This is only one example of the numerous cooling water exchangers needed for the entire AIR TO FUELS™ process even when optimally heat integrated. Energy balances and utility requirements for each of the four major sections of the process are included in **Tables 14.1 - 14.5**.

Table 14.1: Carbon Capture Energy Balance.

Block	Block Type	Duty (Btu/hr)	Utility
AIRSEP	FLASH2	0	--
CACO3SPL	SSPLIT	0	--
CACO3WC	MIXER	0	--
CAHYDRHX	HEATX	2063675.67	Cooling Water
CAOCO2SP	FLASH2	8.12E-08	--
CAOH2MIX	MIXER	0	--
CAOH2REC	MIXER	0	--
CAOH2SPL	FSPLIT	0	--
CAOHX	HEATX	26610441.38	Cooling Water
CAPUMP	PUMP	2391.7642	--
CO3FLASH	FLASH2	-0.000000095	--
H2OHYD1	HEATX	2101149.3	--
H2OHYD2	HEATER	1570000	LPS
HYDRATOR	RSTOIC	-45535000	--
KCACENT	CFUGE	2784.1	--
KILN	RSTOIC	114000000	--
KILNHT	HEATER	46920000	Fuel Gas
KOHMIX	MIXER	0	--
KOHPUMP	PUMP	1201948.021	--
KOHSPLIT	FSPLIT	0	--
PELLETRX	RSTOIC	-11133000	--
PELLMIX	MIXER	0	--
RECSPL	FSPLIT	0	--
SATFLASH	FLASH2	4744.1	--
SCREWHTR	HEATER	-0.000000095	--
SCREWHX	HEATX	26732271.99	--
SCRUBBER	RSTOIC	-1556900000	--
--	Net Duty	-1392358594	--

Table 14.2: Water-Gas Shift Energy Balance.

Block	Block Type	Duty (BTU/hr)	Utility
COMP1	COMP	3157281.41	--
COMP2	COMP	3126061.254	--
COMP3	COMP	987065.8188	--
FLUECOMP	COMP	295907.0313	--
COMP1HX	HEATX	3246910.152	Cooling Water
COMP2HX	HEATX	3115767.748	Cooling Water
COMP3HX	HEATX	711090.6715	--
ECONOM1	HEATX	58859803.47	--
ECONOM2	HEATX	20385457	--
WGSFLAHX	HEATX	47667486.14	Cooling Water
FEEDHEAT	HEATER	4.51E+07	Fuel Gas
FLUFLASH	FLASH2	1.13E+07	--
HTWGS	RGIBBS	0	--
--	Duty	1.98E+08	--

Table 14.3: Fischer-Tropsch Energy Balance.

Block	Block Type	Duty (Btu/hr)	Utility
FTFEEDHX	HEATX	1.64E+07	--
FTPRODHX	HEATX	1.77E+07	Cooling Water
FTHEAT	HEATER	2.45E+06	Fuel Gas
FTREACT	RSTOIC	-5.89E+07	--
--	Net Duty	-2.24E+07	--

Table 14.4: Separations Energy Balance

Block	Block Type	Duty (Btu/hr)	Utility
COOLER1	HEATER	-6400000	Ethylene
DECANT1	DECANTER	27548	--
DECANT2	DECANTER	-34081	--
DECANTH	HEATER	2900000	Fuel Gas
DIST1	RADFRAC	439120	Ammonia, LPS
FLASH1	FLASH2	-4300000	--
FLASH3	FLASH2	-390000	--
FLASH4	FLASH2	2636	--
FLASHLUB	FLASH2	0.0017	--
FUELHEAT	HEATER	1970000	MPS
LIQ2HX1	HEATX	105835	--
LIQ2FLAH	HEATER	3270000	MPS
LUBEHEAT	HEATER	3962	Fuel Gas
LUBEHX	HEATX	4774	--
--	Net Duty	-2400205.998	--

Table 14.5: Overall Utility Requirements

	CO_2 Capture	**WGS**	**Fischer-Tropsch**	**Separation**
Cooling Water (lb/hr)	1.00E+06	1.08E+05	5.83E+05	--
Chilled Water (5-15°C) (BTU/hr)	7.86E+08	--	--	--
Chilled Ammonia (BTU/hr)	--	--	--	6.66E+06
Chilled Ethylene (BTU/hr)	--	--	--	6.40E+06
LPS, 30psig (BTU/hr)	1.57E+06	--	--	7.10E+06
MPS, 150psig (BTU/hr)	--	--	--	5.24E+06
Fuel Gas (BTU/hr)	4.69E+07	4.51E+07	2.45E+06	-7.14E+07

Section 15

Equipment List & Unit Descriptions

Equipment List & Unit Descriptions

Section 15.1: Equipment Heuristics

The AIR TO FUELS™ process includes a vast number of pieces of equipment, many of which were designed and priced on the basis of similar heuristics. For specific flow amount of each component through each piece of equipment, as well as temperature and pressure data, refer to **Section 19: Specification Sheets**.

Section 15.2: Material of Construction

In general, the following steps were followed when choosing a material of construction for a standard piece of equipment. Firstly, chemical compounds passing through said piece of equipment are considered. If any water is processed, at a minimum, the material of construction must be stainless steel to offset corrosion. Building upon this, if elemental hydrogen is present, embrittlement issues and corrosion are a concern and the material of construction must be Monel, a nickel alloy resistant to both. Only in cases in which streams with no “problem” chemicals is the “cheapest first” heuristic applied and carbon steel used as the material of construction.

Section 15.3: Standard Sizing and Pricing

For standard industrial equipment, sizing equations provided in Seider et al. (2017), were used to both size and price. This standard applies to the following types of process blocks: flash drums, decanters, fired heaters, pumps, compressors, blowers, and distillation columns.

Additionally, standards for material of construction and typical equipment sizes have been taken from both literature searches and from tables in Seider et al. (2017).[33]

Section 15.4: Specialized Equipment

Due to the nature of the AIR TO FUELS™ process, several pieces of equipment are not standard in industrial chemical processing plants. This necessitates a closer look at literature sources or discussions with industrial consultants. Such non-standard equipment pieces include the carbon capture fan mechanism, the decalcination process, the water-gas shift reactor, and the Fischer-Tropsch reactor. For simplicity, it was decided between the group and various industrial consultants that the carbon capture system be modeled as a fan bank with a cooling tower, as this allots for the necessary cost allocation for a superstructure to support the fans. Suggestions from industrial consultants also provided the final design for the decalcination process - that of a screw extruder to dry the wet calcium carbonate, followed by a rotary cement kiln lined with refractory brick and sealed to prevent the escape of gaseous product (it was eventually discovered that this is the procedure standard in the carbon capture industry). In regards to the water-gas shift reactor, literature specifications were used to determine both the catalyst and typical size. The Fischer-Tropsch reactor designed much the same way - with specifications provided by Sasol.[37]

Section 16

Specification Sheets

Specification Sheets

The detailed specifications for each piece of equipment in the four steps of our AIR TO FUELS™ fuel synthesis plant are included in this section. For any shell and tube heat exchanger models, design sheets generated by ASPEN's internal heat exchanger design software are included.

Section 16.1: Carbon Dioxide Capture & Purification

AIRSEP				
Identification	Item	Two-phase Flash Drum	**Date**	23-Apr-19
	Item No.	C-F100	**By**	TD, KK, JP
	No. Required	1		
Function	To separate excess air from the liquid flow that continues on to the reactor			
Operation	Semi-Continous			

Property Variables	**Vapor**	**Liquid**
Temperature (°C)	25.0	25.0
Pressure (psi)	14.5	14.5
Composition		
TOTAL (lb/hr)	153,572,782	41,132,107
Water	1,173,576	23,514,033
O_2	35,472,286	57
N_2	116,926,920	96
K_2CO_3	--	219,066
K^+	--	12,003,064
OH^-	--	4,993,368
$Ca(OH)^+$	--	12
$HCO3^-$	--	4.8
CO_3^{2-}	--	402,405

Design Data			
Temperature (°C)	25.0	Material of Construction	316 Stainless Steel
Pressure (psi)	14.5	Orientation	Vertical
Diameter (ft)	33.3	Volume (ft^3)	115,705
Height (ft)	133		

Utilities	
Controls	Assuming the liquid is 50% the volume of the flash drum
Tolerances	
Comments & Drawings	Corrosion is a concern, so 316 Stainless Steel alloy is used for greater durability

CAHYDRHX

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	C-X200	**By**	TD, KK, JP
	No. Required	1		

Function To cool recycled $Ca(OH)_2$ to room temperature

Operation Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	55.2-25.0	5.00-15.0
Pressure (psi)	29.0-27.8	14.5-13.1
Pressure Drop (psi)	1.17	1.36
Material of Construction	Stainless Steel	Carbon Steel
Number of Tubes	--	61
Composition		
TOTAL (lb/hr)	117,527	114,498
Water	5,941	114,498
$Ca(OH)_2$	111,567	--
Ca^{2+}	2.5	--
$Ca(OH)^+$	14	--
OH^-	2.5	--

Design Data

Area (ft^2)	97.2	Heat Duty (BTU/hr)	2.06E+06
Shell Passes	1	Tube Passes	1

Utilities Cooling Water

Controls

Tolerances

Comments & Drawings Corrosion hazard from dissolved OH^- ions

CAPUMP

Identification	Item	Centrifugal Pump	**Date**	23-Apr-19
	Item No.	C-P100	**By**	TD, KK, JP
	No. Required	1		

Function To increase the pressure of $Ca(OH)_2$ solution to induce flow

Operation Continuous

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	55.0	55.0
Pressure (psi)	14.5	29
Composition		
TOTAL (lb/hr)	117,442	117,442
Water	5,871	5,871
$Ca(OH)_2$	111,565	111,565
OH^-	2.5	2.5
Ca^{2+}	2.5	2.5
$Ca(OH)^+$	1.4	1.4

Design Data

Temperature (°C)	55.0	Material of Construction	316 Stainless Steel
Pressure (psi)	14.5 - 29	Orientation	N/A

Utilities

Controls

Tolerances

Comments & Drawings Stainless steel used for construction material due to corrosion concerns

H2OHYD1

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	C-X400	**By**	TD, KK, JP
	No. Required	1		

Function	Preheats water for entry into hydrator
Operation	Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	55.2-25.0	5.00-15.0
Pressure (psi)	29.0-27.8	14.5-13.1
Pressure Drop (psi)	1.17	1.36
Material of Construction	Stainless Steel	Carbon Steel
Number of Tubes	--	61
Composition		
TOTAL (lb/hr)	117,527	114,498
Water	5,941	114,498
$Ca(OH)_2$	111,567	--
Ca^{2+}	2.5	--
$Ca(OH)^+$	14	--
OH^-	2.5	--

Design Data			
Area (ft^2)	97.2	Heat Duty (BTU/hr)	2.06E+06
Shell Passes	1	Tube Passes	1

Utilities	Process Water
Controls	
Tolerances	
Comments & Drawings	

H2OHYD2

Identification	Item	Steam-Heated Exchanger	**Date**	16-Apr-19
	Item No.	C-E400	**By**	TD, KK, JP
	No. Required	1		

Function To complete preheating of water prior to entry to hydrolyzer

Operation Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	135-121	62.2-90.0
Pressure (psi)	30-29.8	14.5-13.6
Pressure Drop (psi)	0.24	0.9
Material of Construction	Stainless Steel	Carbon Steel
Number of Tubes	--	42
Composition		
TOTAL (lb/hr)	1,635	31,413
Water	1635 (lps)	31,413

Design Data

Area (ft^2)	30.4	Heat Duty (BTU/hr)	1.57E+06
Shell Passes	1	Tube Passes	2

Utilities Low pressure steam (30 psi)

Controls

Tolerances

Comments & Drawings

HYDRATOR

Identification	Item	Hydrator	**Date**	23-Apr-19
	Item No.	C-R400	**By**	TD, KK, JP
	No. Required	1		

Function To regenerate $Ca(OH)_2$ used in the pellet reactor as a measure of economizing

Operation Semi-Continuous

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	90.0	90.0
Pressure (psi)	29	29
Composition		
TOTAL (lb/hr)	119,367	119,364
Water	31,169	2,833
CaO	88,198	0
$Ca(OH)_2$	0	116,531

Design Data

Temperature (°C)	90.0	Material of Construction	316 Stainless Steel
Pressure (psi)	29	Orientation	Vertical
Diameter (ft)	7.7	Volume (ft^3)	1,416
Height (ft)	31		

Utilities

Controls Assuming the reactor is 1.5*maximum volume of liquid

Tolerances

Comments & Drawings Corrosion is a concern, so 316 Stainless Steel alloy is used for greater durability

KCACENT

Identification	Item	Centrifugal Solids Separator	**Date**	23-Apr-19
	Item No.	C-S201	**By**	TD, KK, JP
	No. Required	1		

Function Centrifuge to separate solid $CaCO_3$ from aqueous CO_3

Operation Continuous

Property Variables	**Solids Stream**	**Liquid Stream**
Temperature (°C)	25.2	25.0
Pressure (psi)	14.5	14.5
Composition		
TOTAL (lb/hr)	206,438	41,081,058
Water	118,161	23,514,033
O_2	0.3	57
N_2	0.5	96
K^+	60,924	12,123,857
OH^-	25,391	5,052,886
$Ca(OH)^+$	--	1
$HCO3^-$	--	4.6
CO_3^{2-}	1,961	390,122
$CaCO_3$	402,811	--
$Ca(OH)_2$	96,677	--

Design Data

Temperature (°C)	25.0	Material of Construction	316 Stainless Steel
Pressure (psi)	14.5	Orientation	Vertical

Utilities

Controls

Tolerances

Comments & Drawings Corrosion is a concern, so 316 Stainless Steel alloy is used for greater durability

KOHPUMP

Identification	Item	Centrifugal Pump	**Date**	23-Apr-19
	Item No.	C-P100	**By**	TD, KK, JP
	No. Required	1		

Function To increase the pressure of aqueous KOH to induce flow

Operation Continuous

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	25.0	25.0
Pressure (psi)	14.5	29
Composition		
TOTAL (lb/hr)	42,231,815	42,270,362
Water	24,669,741	24,708,288
CO_2	--	--
O_2	--	--
N_2	--	--
K_2CO_3	--	--
K^+	12,126,593	12,126,593
OH^-	5,065,470	5,065,470
$Ca(OH)_2$	0.1	0
$Ca(OH)^+$	1.1	1.1
$HCO3^-$	4.2	4.2
CO_3^{2-}	370,005	370,005

Design Data

Temperature (°C)	30.0	Material of Construction	316 Stainless Steel
Pressure (psi)	14.5 - 29	Orientation	N/A

Utilities

Controls

Tolerances

Comments & Drawings Stainless steel used for construction material due to corrosion concerns

PELLETRX

Identification	Item	Pellet Reactor	**Date**	23-Apr-19
	Item No.	C-R200	**By**	TD, KK, JP
	No. Required	1		

Function	Pseudo-CSTR for the double displacement reaction to produce $CaCO_3$
Operation	Semi-Continuous

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	25.2	25.0
Pressure (psi)	14.5	14.5
Composition		
TOTAL (lb/hr)	40,654,217	40,964,656
Water	23,000,000	23,514,033
O_2	57	57
N_2	96	96
K_2CO_3	219,000	--
K^+	12,003,064	12,003,064
OH^-	5,045,000	5,045,000
$Ca(OH)^+$	--	--
$HCO3^-$	--	--
CO_3^{2-}	387,000	402,405
$CaCO_3$	403,000	556,578
$Ca(OH)_2$	210,595	96,775

Design Data			
Temperature (°C)	25.0	Material of Construction	316 Stainless Steel
Pressure (psi)	14.5	Orientation	Vertical
Diameter (ft)	61.0	Volume (ft^3)	704,715
Height (ft)	243		

Utilities	
Controls	Assuming the reactor is 1.5*maximum volume of liquid
Tolerances	
Comments & Drawings	Corrosion is a concern, so 316 Stainless Steel alloy is used for greater durability

SCRUBBER

Identification	Item	Fan bank (Modelled as reactor)	**Date**	23-Apr-19
	Item No.	C-R100	**By**	TD, KK, JP
	No. Required	1		

Function To scrub carbon dioxide from the air with 75% efficiency

Operation Continuous

Property Variables	**Reactor Inlet**	**Reactor Outlet**
Temperature (°C)	25.0	25.0
Pressure (psi)	14.5	14.5
Composition		
TOTAL (lb/hr)	194,724,178	194,724,634
Water	24,669,741	24,708,288
CO_2	93,012	--
O_2	35,472,340	35,472,340
N_2	116,927,011	116,927,011
K_2CO_3	--	219,066
K^+	12,126,593	12,002,673
OH^-	5,065,470	4,993,538
$Ca(OH)_2$	0.1	--
$Ca(OH)^+$	1.1	1.2
$HCO3^-$	4.2	4.8
CO_3^{2-}	370,005	401,711

Design Data

Temperature (°C)	25.0	Material of Construction	316 Stainless Steel
Pressure (psi)	14.5	Orientation	Vertical

Utilities

Controls

Tolerances

Comments & Drawings This "reactor" is only here for mass balance purposes. The actual reactor will be composed of the fan bank and the cooling tower superstructure

Section 16.2: Syngas Production

COMP1				
Identification	Item	Centrifugal Compressor	**Date**	23-Apr-19
	Item No.	C-W100	**By**	TD, KK, JP
	No. Required	1		
Function	Compress incoming carbon dioxide stream			
Operation	Continuous			
Property Variables	**Suction Side**		**Discharge Side**	
Temperature (°C)	52.8		166	
Pressure (psi)	29.0		87.0	
Volume Flow (CFM)	5736		2576	
Composition				
TOTAL (lb/hr)	69,779		69,779	
CO_2	69,779		69,779	
Design Data				
Driver Type	Electric	Efficiency	0.75 Polytropic	
Shaft Power (HP)	1241	Material of Construction	Carbon Steel	
Utilities				
Controls				
Tolerances				
Comments & Drawings				

COMP1HX

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	X-W100	**By**	TD, KK, JP
	No. Required	1		
Function	Cool compressor outflow with cooling water			
Operation	Continuous			

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	166-50.0	32.2-48.9
Pressure (psi)	84.0-83.7	14.5-14.1
Pressure Drop (psi)	3.35	0.41
Material of Construction	Carbon Steel	Carbon Steel
Number of Tubes	--	330
Composition		
TOTAL (lb/hr)	69,779	107,760
CO_2	69,779	--
Water	--	107,760

Design Data			
Area (ft^2)	589	Heat Duty (BTU/hr)	3.23E+06
Shell Passes	1	Tube Passes	1

Utilities	Cooling Water
Controls	
Tolerances	Water must not exceed 48.89°C (120°F) due to salt precipitation
Comments & Drawings	

COMP2

Identification	Item	Centrifugal Compressor	**Date**	23-Apr-19
	Item No.	C-W101	**By**	TD, KK, JP
	No. Required	1		
Function	Compress incoming carbon dioxide for WGS reactor			
Operation	Continuous			

Property Variables	**Suction Side**	**Discharge Side**
Temperature (°C)	49.4	162
Pressure (psi)	83.7	251
Volume Flow (CFM)	1967	884
Composition		
TOTAL (lb/hr)	69,779	69,779
CO_2	69,779	69,779

Design Data			
Driver Type	Electric	Efficiency	0.75 Polytropic
Shaft Power (HP)	1229	Material of Construction	Carbon Steel

Utilities	
Controls	
Tolerances	
Comments & Drawings	

COMP2HX

Identification	Item	Countercurrent Shell and Tube	**Date**	23-Apr-19
	Item No.	X-W101	**By**	TD, KK, JP
	No. Required	1		

Function	Cool carbon dioxide stream exiting		
Operation			
Property Variables	**Shell Side**	**Tube Side**	
Temperature (°C)	163-50	32.2-48.9	
Pressure (psi)	261-257	14.5-14.0	
Pressure Drop (psi)	3.68	0.52	
Material of Construction	Carbon Steel	Carbon Steel	
Number of Tubes	--	153	
Composition			
TOTAL (lb/hr)	69,779	104,466	
CO_2	69,779	104,466	
Water	--	--	
Design Data			
Area (ft^2)	392	Heat Duty (BTU/hr)	3.13E+06
Shell Passes	1	Tube Passes	1
Utilities	Cooling Water		
Controls			
Tolerances	Water must not exceed 48.89°C (120°F) due to salt precipitation		
Comments & Drawings			

COMP3

Identification	Item	Centrifugal Compressor	**Date**	23-Apr-19
	Item No.	C-W102	**By**	TD, KK, JP
	No. Required	1		

Function	Compress incoming carbon dioxide		
Operation	Continuous		
Property Variables	**Suction Side**	**Discharge Side**	
Temperature (°C)	49.8	86.6	
Pressure (psi)	247	363	
Volume Flow (CFM)	667	506	
Composition			
TOTAL (lb/hr)	69,779	69,779	
CO_2	69,779	69,779	
Design Data			
Driver Type	Electric	Efficiency	0.75 Polytropic
Shaft Power (HP)	388	Material of Construction	Carbon Steel
Utilities			
Controls			
Tolerances			
Comments & Drawings			

COMP3HX

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	X-W102	**By**	TD, KK, JP
	No. Required	1		

Function	Cool carbon dioxide stream exiting the third compressor
Operation	Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	81.5-60.2	32.4-37.0
Pressure (psi)	363-360	363-357
Pressure Drop (psi)	2.22	5.95
Material of Construction	Monel	Monel
Number of Tubes	--	119
Composition		
TOTAL (lb/hr)	69,779	85,761
CO_2	69,779	69,779
H_2	--	15,982

Design Data

Area (ft^2)	85.9	Heat Duty (BTU/hr)	5.71E+05
Shell Passes	1	Tube Passes	1

Utilities	None
Controls	
Tolerances	H_2 embrittlement is a concern. Mitigated through Monel material
Comments & Drawings	

ECONOM1

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	X-W103	**By**	TD, KK, JP
	No. Required	1		

Function Process-to-process heat exchanger to pre-heat the WGS feed

Operation Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	500-80.4	63.4-305
Pressure (psi)	363-362	363-362
Pressure Drop (psi)	0.38	0.31
Material of Construction	Monel	Monel
Number of Tubes	--	613
Composition		
TOTAL (lb/hr)	77,694	155,387
CO	29,960	29,933
CO_2	22,522	92,160
H_2	13,823	29,804
Water	11,389	3,491

Design Data

Area (ft^2)	170,507.5	Heat Duty (BTU/hr)	5.88E+07
Shell Passes	1 Series / 6 Parallel	Tube Passes	1

Utilities None

Controls

Tolerances H_2 embrittlement is a concern. Mitigated through Monel material

Comments & Drawings

ECONOM2

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	X-W104	**By**	TD, KK, JP
	No. Required	1		

Function Process-to-process heat exchanger to pre-heat the WGS feed

Operation Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	500-333	305-388
Pressure (psi)	363-358	363-356
Pressure Drop (psi)	4.96	6.51
Material of Construction	Monel	Monel
Number of Tubes	--	497
Composition		
TOTAL (lb/hr)	77,694	155,387
CO	29,960	29,933
CO_2	22,522	92,160
H_2	13,823	29,804
Water	11,389	3,491

Design Data

Area (ft^2)	1365.5	Heat Duty (BTU/hr)	2.04E+07
Shell Passes	1	Tube Passes	1

Utilities None

Controls

Tolerances H_2 embrittlement is a concern. Mitigated through Monel material

Comments & Drawings

FEEDHEAT

Identification	Item	Gas Fired Heater	**Date**	23-Apr-19
	Item No.	H-W100	**By**	TD, KK, JP
	No. Required	1		

Function Finish heating feed up to WGS inlet temperature

Operation Continuous

Property Variables	**Feed Side**	**Discharge Side**
Temperature (°C)	388	567.72
Pressure (psi)	363	363
Composition		
TOTAL (lb/hr)	155,382	155,382
CO	29,922	29,922
CO_2	92,155	92,155
H_2	29,799	29,799
H_2O	3,506	3,506

Design Data

Heat Duty (BTU/hr) 4.51E+07 Material of Construction Cr-Mo Alloy

Utilities None

Controls

Tolerances H_2 embrittlement is a concern. Mitigated through Cr-Mo alloy material

Comments & Drawings

FLUECOMP

Identification	Item	Centrifugal Compressor	**Date**	16-Apr-19
	Item No.	C-W103	**By**	TD, KK, JP
	No. Required	1		

Function Compress recycled reactor effluent after removal of water

Operation Continuous

Property Variables	**Suction Side**	**Discharge Side**
Temperature (°C)	84.3	87.0
Pressure (psi)	358	365
Volume Flow (CFM)	2774	2739
Composition		
TOTAL (lb/hr)	73,859	73,859
CO	29,922	29,922
CO_2	22,388	22,388
H_2	13,819	13,819
H_2O	7,730	7,730

Design Data

Driver Type Electric Efficiency 0.75 Polytropic

Shaft Power (HP) 166 Material of Construction Nickel Alloy

Utilities

Controls H_2 embrittlement is a concern, as is corrosion from hot steam. Ni alloy is thus used.

Tolerances

Comments & Drawings

FLUFLASH

Identification	Item	Two-phase Flash Drum	**Date**	23-Apr-19
	Item No.	F-W100	**By**	TD, KK, JP
	No. Required	1		

Function Flash the WGS reactor effluent to remove 95% water from the gas stream

Operation Continuous

Property Variables	**Vapor**	**Liquid**
Temperature (°C)	84.3	84.3
Pressure (psi)	358	358
Composition		
TOTAL (lb/hr)	139,270	16,110
CO	59,843	54
CO_2	44,776	279
H_2	27,639	2.4
Water	7,012	15,776

Design Data

Temperature (°C)	84.3	Material of Construction	Monel
Pressure (psi)	358	Orientation	Vertical
Diameter (ft)	4.4	Volume (ft^3)	138
Height (ft)	17.8		

Utilities

Controls Assuming the liquid is 50% the volume of the flash drum

Tolerances

Comments & Drawings H_2 embrittlement is a concern, so Monel alloy is used

HTWGS

Identification	Item	Fan bank (Modelled as reactor)	**Date**	23-Apr-19
	Item No.	R-W100	**By**	TD, KK, JP
	No. Required	1		

Function High-temperature WGS reactor for CO_2 reduction to CO

Operation Continuous

Property Variables	**Reactor Inlet**	**Reactor Outlet**
Temperature (°C)	568	500
Pressure (psi)	363	363
Composition		
TOTAL (lb/hr)	155,382	155,381
CO	29,922	59,899
CO_2	92,155	45,055
H_2	29,799	27,641
H_2O	3,506	22,787

Design Data

Temperature (°C)	568-200 (Adiabatic)	Material of Construction	Monel
Pressure (psi)	363	Orientation	Vertical
Diameter (ft)	2.3	Volume (ft^3)	20.3
Height (ft)	4.7	Catalyst Void Fraction	0.38

Utilities

Controls

Tolerances Hydrogen embrittlement is a concern, so Monel alloy is used

Comments & Drawings Adiabatic reactor, packed bed

WGSFLAHX

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	X-W105	**By**	TD, KK, JP
	No. Required	1		

Function Cool reactor effluent stream in preparation for flash drum

Operation Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	172-84.4	32.2-48.9
Pressure (psi)	363-358	14.5-13.3
Pressure Drop (psi)	4.92	1.19
Material of Construction	Monel	Monel
Number of Tubes	--	613
Composition		
TOTAL (lb/hr)	155,387	1,211,968
CO	59,919	--
CO_2	45,045	--
H_2	27,645	--
Water	22,778	1,211,968

Design Data

Area (ft^2)	1025.5	Heat Duty (BTU/hr)	3.63E+07
Shell Passes	1	Tube Passes	1

Utilities None

Controls

Tolerances H_2 embrittlement is a concern. Mitigated through Monel material

Comments & Drawings

Section 16.3: Fischer-Tropsch Fuel Synthesis

FTFEEDHX

Identification	Item	Shell and Tube Heat Exchanger	**Date**	16-Apr-19
	Item No.	X-F100	**By**	TD, KK, JP
	No. Required	1		

Function	Preheat syngas feed going into FT plant
Operation	Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	300-145	89.5-270
Pressure (psi)	363-356	363-358
Pressure Drop (psi)	6.63	4.12
Material of Construction	Stainless Steel	Stainless Steel
Composition		
TOTAL (lb/hr)	69,627	54,193
CH_4	314	--
C_2H_6	511	--
C_3H_8	650	--
C_4H_{10}	747	--
C_5H_{12}	806	--
C_6H_{14}	838	--
C_7H_{16}	849	--
C_8H_{18}	841	--
C_9H_{20}	822	--
$C_{10}H_{22}$	794	--
$C_{11}H_{24}$	758	--
$C_{12}H_{26}$	719	--
$C_{13}H_{28}$	676	--
$C_{14}H_{30}$	633	--
$C_{15}H_{32}$	590	--
$C_{16}H_{34}$	544	--
$C_{17}H_{36}$	499	--
$C_{18}H_{38}$	468	--
$C_{19}H_{40}$	423	--
$C_{20}H_{42}$	392	--
$C_{21}H_{44}$	362	--
$C_{22}H_{46}$	317	--
$C_{23}H_{48}$	296	--
$C_{24}H_{50}$	268	--
$C_{25}H_{52}$	243	--
$C_{26}H_{54}$	220	--
$C_{27}H_{56}$	199	--
$C_{28}H_{58}$	179	--
$C_{29}H_{60}$	161	--
$C_{30}H_{62}$	146	--
CO	43	23,298
CO_2	22,382	17,421
H_2	9,221	10,758
Water	22,716	2,717

Design Data			
Area (ft^2)	3330	Heat Duty (BTU/hr)	2.02E+07
Shell Passes	2 Series / 2 Para.	Tube Passes	1

Utilities	None
Controls	
Tolerances	
Comments & Drawings	

FTHEAT

Identification	Item	Gas Fired Heater	**Date**	23-Apr-19
	Item No.	H-F100	**By**	TD, KK, JP
	No. Required	1		

Function	Finish heating feed up to FT reactor inlet temperature
Operation	Continuous

Property Variables	**Feed Side**	**Discharge Side**
Temperature (°C)	272	300
Pressure (psi)	363	363
Composition		
TOTAL (lb/hr)	54,193	54,193
CO	23,298	23,298
CO_2	17,421	17,421
H_2	10,758	10,758
H_2O	2,717	2,717

Design Data

Heat Duty (BTU/hr) 2.45E+06 Material of Construction Cr-Mo alloy

Utilities	None
Controls	
Tolerances	H_2 embrittlement is a concern. Mitigated through Cr-Mo alloy material
Comments & Drawings	

FTPRODHX

Identification	Item	Shell and Tube Heat Exchanger	**Date**	16-Apr-19
	Item No.	X-F101	**By**	TD, KK, JP
	No. Required	1		

Function	Cool FT products going to separation system
Operation	Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	153.24-79.93	32.22-49.89
Pressure (psi)	356-354	14.5-10.2
Pressure Drop (psi)	1.60	4.26
Material of Construction	Stainless Steel	Carbon Steel
Number of Tubes	--	450
Composition		
TOTAL (lb/hr)	69,627	725,910
CH_4	314	--
C_2H_6	511	--
C_3H_8	650	--
C_4H_{10}	747	--
C_5H_{12}	806	--
C_6H_{14}	838	--
C_7H_{16}	849	--
C_8H_{18}	841	--
C_9H_{20}	822	--
$C_{10}H_{22}$	794	--
$C_{11}H_{24}$	758	--
$C_{12}H_{26}$	719	--
$C_{13}H_{28}$	676	--
$C_{14}H_{30}$	633	--
$C_{15}H_{32}$	590	--
$C_{16}H_{34}$	544	--
$C_{17}H_{36}$	499	--
$C_{18}H_{38}$	468	--
$C_{19}H_{40}$	423	--
$C_{20}H_{42}$	392	--
$C_{21}H_{44}$	362	--
$C_{22}H_{46}$	317	--
$C_{23}H_{48}$	296	--
$C_{24}H_{50}$	268	--
$C_{25}H_{52}$	243	--
$C_{26}H_{54}$	220	--
$C_{27}H_{56}$	199	--
$C_{28}H_{58}$	179	--
$C_{29}H_{60}$	161	--
$C_{30}H_{62}$	146	--
CO	43	--
CO_2	22,382	--
H_2	9,221	--
Water	22,716	725,910

Design Data			
Area (ft^2)	406.52	Heat Duty (BTU/hr)	2.39E+07
Shell Passes	1	Tube Passes	2

Utilities	Cooling water

FTREACTOR

Identification	Item	Slurry-bed Reactor	**Date**	16-Apr-19
	Item No.	R-F100	**By**	TD, KK, JP
	No. Required	1		

Function Vessel for reaction of syngas and hydrogen to produce synthetic fuels

Operation Semi-Continuous

Property Variables	**Reactor Inlet**	**Reactor Outlet**
Temperature (°C)	300	300
Pressure (psi)	363	363
Composition		
TOTAL (lb/hr)	54,193	119,496
CO	23,298	74
CO_2	17,421	38,413
H_2	10,758	15,825
Water	2,717	38,986
CH_4	--	538
C_2H_6	--	877
C_3H_8	--	1,116
C_4H_{10}	--	1,282
C_5H_{12}	--	1,384
C_6H_{14}	--	1,438
C_7H_{16}	--	1,457
C_8H_{18}	--	1,443
C_9H_{20}	--	1,411
$C_{10}H_{22}$	--	1,362
$C_{11}H_{24}$	--	1,300
$C_{12}H_{26}$	--	1,234
$C_{13}H_{28}$	--	1,160
$C_{14}H_{30}$	--	1,086
$C_{15}H_{32}$	--	1,013
$C_{16}H_{34}$	--	934
$C_{17}H_{36}$	--	856
$C_{18}H_{38}$	--	804
$C_{19}H_{40}$	--	726
$C_{20}H_{42}$	--	674
$C_{21}H_{44}$	--	622
$C_{22}H_{46}$	--	544
$C_{23}H_{48}$	--	507
$C_{24}H_{50}$	--	461
$C_{25}H_{52}$	--	417
$C_{26}H_{54}$	--	378
$C_{27}H_{56}$	--	341
$C_{28}H_{58}$	--	308
$C_{29}H_{60}$	--	277
$C_{30}H_{62}$	--	250

Design Data

Temperature (°C)	300	Material of Construction	316 Stainless Steel
Pressure (psi)	363	Orientation	Vertical
Diameter (ft)	16	Volume (ft^3)	14476.5
Length (ft.)	72	Catalyst	20% Co on SBA-15

Utilities

Controls

Tolerances

Comments & Drawings 4.7 sec residence time

Section 16.4: Separation Systems

COOLER1				
Identification	Item	Refrigerated Cooler	**Date**	23-Apr-19
	Item No.	S-E100	**By**	TD, KK, JP
	No. Required	1		
Function	To cool gaseous product for the removal of carbon dioxide and hydrogen gas			
Operation	Continuous			

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	50.4	-54.0
Pressure (psi)	362.5	362.5
Composition		
TOTAL (lb/hr)	26,463	26,463
CO	33	33
CO_2	15,915	15,915
H_2	7,118	7,118.0
Water	351	351
CH_4	241	241
C_2H_6	393	393
C_3H_8	494	494
C_4H_{10}	548	548
C_5H_{12}	546	546
C_6H_{14}	455	455
C_7H_{16}	239	239
C_8H_{18}	61	61
C_9H_{20}	53	53
$C_{10}H_{22}$	16	16
$C_{11}H_{24}$	0	0
$C_{12}H_{26}$	0	0
$C_{13}H_{28}$	0	0
$C_{14}H_{30}$	0	0
$C_{15}H_{32}$	0	0
$C_{16}H_{34}$	0	0
$C_{17}H_{36}$	0	0
$C_{18}H_{38}$	0	0
$C_{19}H_{40}$	0	0
$C_{20}H_{42}$	0	0
$C_{21}H_{44}$	0	0
$C_{22}H_{46}$	0	0
$C_{23}H_{48}$	0	0
$C_{24}H_{50}$	0	0
$C_{25}H_{52}$	0	0
$C_{26}H_{54}$	0	0
$C_{27}H_{56}$	0	0
$C_{28}H_{58}$	0	0
$C_{29}H_{60}$	0	0
$C_{30}H_{62}$	0	0

Design Data			
Temperature (°C)	120	Material of Construction	Cr Mo Alloy
Pressure (psi)	362.6	Orientation	Horizontal
Diameter (ft)	3.2	Volume (ft^3)	105
Height (ft)	12.9		

Utilities	Refrigerant (Ethylene)
Controls	
Tolerances	
Comments & Drawings	This cooling must be accomplished with refrigerant

DECANT1

Identification	Item	Water-Hydrocarbon Decanter	**Date**	23-Apr-19
	Item No.	S-D100	**By**	TD, KK, JP
	No. Required	1		

Function	To separate water and alkane product
Operation	Semi-Continuous

Property Variables	**Liquid 1**	**Liquid 2**
Temperature (°C)	120	120.0
Pressure (psi)	362.5	362.5
Composition		
TOTAL (lb/hr)	7,520	19,156
CO	0	0
CO_2	0	515
H_2	0	3.8
Water	465	17,076
CH_4	0	0
C_2H_6	0	0
C_3H_8	7	0
C_4H_{10}	22	0
C_5H_{12}	77	0
C_6H_{14}	191	0
C_7H_{16}	417	0
C_8H_{18}	587	0
C_9H_{20}	521	57
$C_{10}H_{22}$	596	0
$C_{11}H_{24}$	575	0
$C_{12}H_{26}$	552	0
$C_{13}H_{28}$	519	0
$C_{14}H_{30}$	486	0
$C_{15}H_{32}$	443	0
$C_{16}H_{34}$	420	0
$C_{17}H_{36}$	353	31
$C_{18}H_{38}$	313	48
$C_{19}H_{40}$	256	71
$C_{20}H_{42}$	205	95
$C_{21}H_{44}$	162	117
$C_{22}H_{46}$	114	129
$C_{23}H_{48}$	87	140
$C_{24}H_{50}$	64	141
$C_{25}H_{52}$	52	136
$C_{26}H_{54}$	36	135
$C_{27}H_{56}$	0	127
$C_{28}H_{58}$	0	125
$C_{29}H_{60}$	0	109
$C_{30}H_{62}$	0	100

Design Data			
Temperature (°C)	120	Material of Construction	Stainless Steel
Pressure (psi)	362.6	Orientation	Horizontal
Diameter (ft)	3.6	Volume (ft^3)	143
Height (ft)	14.3		

Utilities	
Controls	Assuming the liquid is 50% the volume of the flash drum
Tolerances	
Comments & Drawings	Corrosion is a concern, so stainless steel is used

DECANT2

Identification	Item	Water-Hydrocarbon Decanter	**Date**	23-Apr-19
	Item No.	S-D101	**By**	TD, KK, JP
	No. Required	1		

Function	To separate water and alkane product
Operation	Semi-Continuous

Property Variables	**Liquid 1**	**Liquid 2**
Temperature (°C)	190	190.0
Pressure (psi)	362.5	362.5
Composition		
TOTAL (lb/hr)	0	19,156
CO	0	0
CO_2	0	515
H_2	0	3.8
Water	0	17,076
CH_4	0	0
C_2H_6	0	0
C_3H_8	0	0
C_4H_{10}	0	0
C_5H_{12}	0	0
C_6H_{14}	0	0
C_7H_{16}	0	0
C_8H_{18}	0	0
C_9H_{20}	0	57
$C_{10}H_{22}$	0	0
$C_{11}H_{24}$	0	0
$C_{12}H_{26}$	0	0
$C_{13}H_{28}$	0	0
$C_{14}H_{30}$	0	0
$C_{15}H_{32}$	0	0
$C_{16}H_{34}$	0	0
$C_{17}H_{36}$	0	31
$C_{18}H_{38}$	0	48
$C_{19}H_{40}$	0	71
$C_{20}H_{42}$	0	95
$C_{21}H_{44}$	0	117
$C_{22}H_{46}$	0	129
$C_{23}H_{48}$	0	140
$C_{24}H_{50}$	0	141
$C_{25}H_{52}$	0	136
$C_{26}H_{54}$	0	135
$C_{27}H_{56}$	0	127
$C_{28}H_{58}$	0	125
$C_{29}H_{60}$	0	109
$C_{30}H_{62}$	0	100

Design Data

Temperature (°C)	120	Material of Construction	Stainless Steel
Pressure (psi)	362.6	Orientation	Horizontal
Diameter (ft)	3.2	Volume (ft^3)	105
Height (ft)	12.9		

Utilities	
Controls	Assuming the liquid is 50% the volume of the flash drum
Tolerances	
Comments & Drawings	Negligible flow rates exit through the other liquid, but does assist in purification

DECANTH

Identification	Item	Gas-fired Heater	**Date**	23-Apr-19
	Item No.	S-H100	**By**	TD, KK, JP
	No. Required	1		

Function	To heat liquid to proper temperature for removal of small amounts of lubricants
Operation	Continous

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	190	350.0
Pressure (psi)	362.6	362.6
Composition		
TOTAL (lb/hr)	19,184	19,184
CO	0	0
CO_2	524	524
H_2	3.8	3.8
Water	17,069	17,069
CH_4	0.14	0.14
C_2H_6	0.16	0.16
C_3H_8	2.70	2.70
C_4H_{10}	5.10	5.10
C_5H_{12}	0.07	0.07
C_6H_{14}	1.23	1.23
C_7H_{16}	0.22	0.22
C_8H_{18}	0.02	0.02
C_9H_{20}	57.90	57.90
$C_{10}H_{22}$	0.15	0.15
$C_{11}H_{24}$	0.08	0.08
$C_{12}H_{26}$	0.08	0.08
$C_{13}H_{28}$	0.08	0.08
$C_{14}H_{30}$	0.08	0.08
$C_{15}H_{32}$	13.70	13.70
$C_{16}H_{34}$	0.08	0.08
$C_{17}H_{36}$	30.50	30.50
$C_{18}H_{38}$	47.70	47.70
$C_{19}H_{40}$	70.70	70.70
$C_{20}H_{42}$	96.20	96.20
$C_{21}H_{44}$	117.30	117.30
$C_{22}H_{46}$	129.26	129.26
$C_{23}H_{48}$	140.22	140.22
$C_{24}H_{50}$	142.40	142.40
$C_{25}H_{52}$	137.40	137.40
$C_{26}H_{54}$	134.40	134.40
$C_{27}H_{56}$	126.60	126.60
$C_{28}H_{58}$	126.60	126.60
$C_{29}H_{60}$	107.70	107.70
$C_{30}H_{62}$	98.90	98.90

Design Data			
Temperature (°C)	350	Material of Construction	Cr Mo Alloy
Pressure (psi)	362.6	Orientation	N/A
Diameter (ft)	N/A	Volume (ft^3)	N/A
Height (ft)	N/A		

Utilities	Fuel gas
Controls	
Tolerances	
Comments & Drawings	Small amounts of lubricants not caught by the tolerace are removed

DIST1

Identification	Item	Distillation Column	**Date**	23-Apr-19
	Item No.	S-C100	**By**	TD, KK, JP
	No. Required	1		

Function To separate remaining light gases from the alkane fuel stream

Operation Semi-Continuous

Property Variables	**Distillate**	**Bottoms**
Temperature (°C)	-27.9	63.2
Pressure (psi)	14.7	14.7
Composition		
TOTAL (lb/hr)	20,941	8,726
CO	0	0
CO_2	2,729	0
H_2	0.7	0
Water	17,191	467
CH_4	35	0
C_2H_6	28	0
C_3H_8	331	0
C_4H_{10}	484	0
C_5H_{12}	142	470
C_6H_{14}	0	644
C_7H_{16}	0	656
C_8H_{18}	0	646
C_9H_{20}	0	573
$C_{10}H_{22}$	0	611
$C_{11}H_{24}$	0	585
$C_{12}H_{26}$	0	558
$C_{13}H_{28}$	0	521
$C_{14}H_{30}$	0	488
$C_{15}H_{32}$	0	440
$C_{16}H_{34}$	0	420
$C_{17}H_{36}$	0	353
$C_{18}H_{38}$	0	313
$C_{19}H_{40}$	0	256
$C_{20}H_{42}$	0	207
$C_{21}H_{44}$	0	162
$C_{22}H_{46}$	0	114
$C_{23}H_{48}$	0	87
$C_{24}H_{50}$	0	67
$C_{25}H_{52}$	0	52
$C_{26}H_{54}$	0	37
$C_{27}H_{56}$	0	0
$C_{28}H_{58}$	0	0
$C_{29}H_{60}$	0	0
$C_{30}H_{62}$	0	0

Design Data

Temperature (°C)	-27.9 to 63.2	Material of Construction	Monel (Hydrogen Concerns)
Pressure (psi)	14.7	Orientation	Vertical
Diameter (ft)	2.2	Volume (ft^3)	N/A
Height (ft)	47.0	No. of Trays	11
Reflux Ratio	5.8	Feed Tray	7
Reboiler Duty (Btu/hr)	7100580.0	Condenser Duty (Btu/hr)	-6,661,460

Utilities Refrigerated ammonia for condenser, pressurized steam for reboiler

Controls

Tolerances

Comments & Drawings Contains condenser, reboiler, reflux accumulator, reflux pump in cost estimates

FLASH1

Identification	Item	Two-phase Flash Drum	**Date**	23-Apr-19
	Item No.	S-F100	**By**	TD, KK, JP
	No. Required	1		

Function	To separate liquid and vapor products from Fischer-Tropsch reactor to prepare for decanting
Operation	Semi-Continuous

Property Variables	**Vapor**	**Liquid**
Temperature (°C)	50.5	50.5
Pressure (psi)	362.6	362.6
Composition		
TOTAL (lb/hr)	26,417	30,384
CO	33	33
CO_2	15,915	1,372
H_2	7,118	4.0
Water	351	17,192
CH_4	241	1.0
C_2H_6	393	1.5
C_3H_8	493	9.0
C_4H_{10}	491	29
C_5H_{12}	546	77
C_6H_{14}	455	191
C_7H_{16}	238	417
C_8H_{18}	61	587
C_9H_{20}	53	580
$C_{10}H_{22}$	17	596
$C_{11}H_{24}$	8.0	803
$C_{12}H_{26}$	2.7	771
$C_{13}H_{28}$	1.0	772
$C_{14}H_{30}$	0.4	730
$C_{15}H_{32}$	--	689
$C_{16}H_{34}$	--	638
$C_{17}H_{36}$	--	589
$C_{18}H_{38}$	--	545
$C_{19}H_{40}$	--	498
$C_{20}H_{42}$	--	451
$C_{21}H_{44}$	--	421
$C_{22}H_{46}$	--	379
$C_{23}H_{48}$	--	348
$C_{24}H_{50}$	--	319
$C_{25}H_{52}$	--	276
$C_{26}H_{54}$	--	258
$C_{27}H_{56}$	--	234
$C_{28}H_{58}$	--	211
$C_{29}H_{60}$	--	191
$C_{30}H_{62}$	--	172

Design Data			
Temperature (°C)	50.5	Material of Construction	Monel
Pressure (psi)	362.6	Orientation	Vertical
Diameter (ft)	3.5	Volume (ft^3)	132
Height (ft)	13.9		

Utilities	
Controls	Assuming the liquid is 50% the volume of the flash drum
Tolerances	
Comments & Drawings	H_2 embrittlement is a concern, so Monel alloy is used

FLASH3

Identification	Item	Two-phase Flash Drum	**Date**	23-Apr-19
	Item No.	S-F101	**By**	TD, KK, JP
	No. Required	1		

Function	To separate CO_2 and hydrogen from the fuel product
Operation	Semi-Continuous

Property Variables	**Vapor**	**Liquid**
Temperature (°C)	-59.6	-59.6
Pressure (psi)	362.6	362.6
Composition		
TOTAL (lb/hr)	22,481	4,469
CO	33	33
CO_2	14,038	1,875
H_2	7,117	0.5
Water	0.03	351
CH_4	207	34
C_2H_6	366	37
C_3H_8	168	325
C_4H_{10}	86	461
C_5H_{12}	11	535
C_6H_{14}	455	453
C_7H_{16}	--	239
C_8H_{18}	--	57
C_9H_{20}	--	53
$C_{10}H_{22}$	--	17
$C_{11}H_{24}$	--	--
$C_{12}H_{26}$	--	--
$C_{13}H_{28}$	--	--
$C_{14}H_{30}$	--	--
$C_{15}H_{32}$	--	--
$C_{16}H_{34}$	--	--
$C_{17}H_{36}$	--	--
$C_{18}H_{38}$	--	--
$C_{19}H_{40}$	--	--
$C_{20}H_{42}$	--	--
$C_{21}H_{44}$	--	--
$C_{22}H_{46}$	--	--
$C_{23}H_{48}$	--	--
$C_{24}H_{50}$	--	--
$C_{25}H_{52}$	--	--
$C_{26}H_{54}$	--	--
$C_{27}H_{56}$	--	--
$C_{28}H_{58}$	--	--
$C_{29}H_{60}$	--	--
$C_{30}H_{62}$	--	--

Design Data			
Temperature (°C)	50.5	Material of Construction	Monel
Pressure (psi)	362.6	Orientation	Vertical
Diameter (ft)	1.9	Volume (ft^3)	20
Height (ft)	7.2		

Utilities	
Controls	Assuming the liquid is 50% the volume of the flash drum
Tolerances	
Comments & Drawings	H_2 embrittlement is a concern, so Monel alloy is used

FLASH4

Identification	Item	Two-phase Flash Drum	**Date**	23-Apr-19
	Item No.	S-F103	**By**	TD, KK, JP
	No. Required	1		

Function To separate gasoline and diesel products

Operation Semi-Continuous

Property Variables	**Vapor**	**Liquid**
Temperature (°C)	170	170.0
Pressure (psi)	14.7	14.7
Composition		
TOTAL (lb/hr)	4,748	3,930
CO	--	--
CO_2	--	--
H_2	--	--
Water	465	--
CH_4	--	--
C_2H_6	--	--
C_3H_8	--	--
C_4H_{10}	--	--
C_5H_{12}	463	--
C_6H_{14}	623	21
C_7H_{16}	616	40
C_8H_{18}	589	62
C_9H_{20}	480	97
$C_{10}H_{22}$	447	165
$C_{11}H_{24}$	366	217
$C_{12}H_{26}$	270	286
$C_{13}H_{28}$	183	338
$C_{14}H_{30}$	130	358
$C_{15}H_{32}$	78	362
$C_{16}H_{34}$	38	380
$C_{17}H_{36}$	--	334
$C_{18}H_{38}$	--	300
$C_{19}H_{40}$	--	250
$C_{20}H_{42}$	--	202
$C_{21}H_{44}$	--	162
$C_{22}H_{46}$	--	114
$C_{23}H_{48}$	--	87
$C_{24}H_{50}$	--	67
$C_{25}H_{52}$	--	52
$C_{26}H_{54}$	--	36
$C_{27}H_{56}$	--	--
$C_{28}H_{58}$	--	--
$C_{29}H_{60}$	--	--
$C_{30}H_{62}$	--	--

Design Data

Temperature (°C)	170	Material of Construction	Stainless Steel
Pressure (psi)	14.7	Orientation	Vertical
Diameter (ft)	2.0	Volume (ft^3)	25
Height (ft)	8.0		

Utilities

Controls Assuming the liquid is 50% the volume of the flash drum

Tolerances

Comments & Drawings Corrosion is a concern, so stainless steel is used

FLASHLUB

Identification	Item	Two-phase Flash Drum	**Date**	23-Apr-19
	Item No.	S-F102	**By**	TD, KK, JP
	No. Required	1		

Function	To separate minimal amounts of lubricants from hydrocarbon stream exiting the decanters
Operation	Semi-Continuous

Property Variables	**Vapor**	**Liquid**
Temperature (°C)	350	350.0
Pressure (psi)	362.6	362.6
Composition		
TOTAL (lb/hr)	2.92E-01	18
CO	0	0
CO_2	0	0
H_2	0	0.0
Water	0	0
CH_4	5.00E-05	4.90E-06
C_2H_6	1.84E-03	3.90E-04
C_3H_8	4.13E-03	1.76E-03
C_4H_{10}	1.38E-02	1.04E-02
C_5H_{12}	1.60E-02	2.33E-02
C_6H_{14}	4.22E-02	8.97E-02
C_7H_{16}	2.07E-02	7.56E-02
C_8H_{18}	2.60E-05	1.70E-03
C_9H_{20}	5.06E-02	0.36
$C_{10}H_{22}$	4.95E-03	7.10E-02
$C_{11}H_{24}$	4.45E-03	6.70E-02
$C_{12}H_{26}$	3.06E-03	6.50E-02
$C_{13}H_{28}$	2.27E-03	6.80E-02
$C_{14}H_{30}$	2.03E-03	6.60E-02
$C_{15}H_{32}$	3.37E-02	1.73
$C_{16}H_{34}$	8.70E-04	5.93E-02
$C_{17}H_{36}$	2.65E-02	2.43
$C_{18}H_{38}$	2.27E-02	2.67
$C_{19}H_{40}$	1.71E-02	2.65
$C_{20}H_{42}$	1.09E-02	2.25
$C_{21}H_{44}$	6.68E-03	1.78
$C_{22}H_{46}$	3.51E-03	1.19
$C_{23}H_{48}$	1.92E-03	0.84
$C_{24}H_{50}$	9.70E-04	0.55
$C_{25}H_{52}$	4.90E-04	0.35
$C_{26}H_{54}$	2.60E-04	0.23
$C_{27}H_{56}$	1.30E-04	0.16
$C_{28}H_{58}$	7.00E-06	0.01
$C_{29}H_{60}$	4.20E-05	0.08
$C_{30}H_{62}$	2.20E-05	0.07

Design Data

Temperature (°C)	350	Material of Construction	Stainless Steel
Pressure (psi)	362.6	Orientation	Vertical
Diameter (ft)	0.4	Volume (ft^3)	approximately .3
Height (ft)	1.4		

Utilities	
Controls	Assuming the liquid is 50% the volume of the flash drum
Tolerances	
Comments & Drawings	Corrosion is a concern, so stainless steel is used, small amounts of lubricants flashed

FUELHEAT

Identification	Item	Gas-fired Heater	**Date**	23-Apr-19
	Item No.	S-E104	**By**	TD, KK, JP
	No. Required	1		

Function To heat fuel product for efficient separation of diesel and gasoline with a flash drum

Operation Continuous

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	63.17	170.0
Pressure (psi)	14.7	14.7
Composition		
TOTAL (lb/hr)	8,717	8,717
CO	--	--
CO_2	--	--
H_2	--	--
Water	466	466
CH_4	--	--
C_2H_6	--	--
C_3H_8	--	--
C_4H_{10}	--	--
C_5H_{12}	470	470
C_6H_{14}	644	644
C_7H_{16}	655	655
C_8H_{18}	648	648
C_9H_{20}	576	576
$C_{10}H_{22}$	611	611
$C_{11}H_{24}$	586	586
$C_{12}H_{26}$	554	554
$C_{13}H_{28}$	519	519
$C_{14}H_{30}$	488	488
$C_{15}H_{32}$	440	440
$C_{16}H_{34}$	420	420
$C_{17}H_{36}$	353	353
$C_{18}H_{38}$	313	313
$C_{19}H_{40}$	256	256
$C_{20}H_{42}$	205	205
$C_{21}H_{44}$	162	162
$C_{22}H_{46}$	114	114
$C_{23}H_{48}$	87	87
$C_{24}H_{50}$	64	64
$C_{25}H_{52}$	49	49
$C_{26}H_{54}$	37	37
$C_{27}H_{56}$	--	--
$C_{28}H_{58}$	--	--
$C_{29}H_{60}$	--	--
$C_{30}H_{62}$	--	--

Design Data

Temperature (°C)	170	Material of Construction	Cr Mo Alloy
Pressure (psi)	14.7	Orientation	N/A
Diameter (ft)	N/A	Volume (ft^3)	N/A
Height (ft)	N/A		

Utilities Fuel Gas

Controls

Tolerances

Comments & Drawings Stainless steel used for construction due to corrosion concerns

LIQ2HX1

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	S-X100	**By**	TD, KK, JP
	No. Required	1		

Function	To heat decanted water and hydrocarbons and cool diesel product
Operation	Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	170-147	120-122.8
Pressure (psi)	363-361	363-356
Pressure Drop (psi)	1.60	7.25
Material of Construction	Stainless Steel	Stainless Steel
Composition		
TOTAL (lb/hr)	19,156	3,930
CH_4	--	--
C_2H_6	--	--
C_3H_8	--	--
C_4H_{10}	--	--
C_5H_{12}	--	--
C_6H_{14}	--	21
C_7H_{16}	--	40
C_8H_{18}	--	62
C_9H_{20}	57	97
$C_{10}H_{22}$	--	165
$C_{11}H_{24}$	--	217
$C_{12}H_{26}$	--	286
$C_{13}H_{28}$	--	338
$C_{14}H_{30}$	--	358
$C_{15}H_{32}$	--	362
$C_{16}H_{34}$	--	380
$C_{17}H_{36}$	31	334
$C_{18}H_{38}$	48	300
$C_{19}H_{40}$	71	250
$C_{20}H_{42}$	95	202
$C_{21}H_{44}$	117	162
$C_{22}H_{46}$	129	114
$C_{23}H_{48}$	140	87
$C_{24}H_{50}$	141	67
$C_{25}H_{52}$	136	52
$C_{26}H_{54}$	135	36
$C_{27}H_{56}$	127	--
$C_{28}H_{58}$	125	--
$C_{29}H_{60}$	109	--
$C_{30}H_{62}$	100	--
CO	--	--
CO_2	515	--
H_2	3.8	--
Water	17,076	--

Design Data			
Area (ft^2)	24.6	Heat Duty (BTU/hr)	1.15E+05
Shell Passes	1 Series / 1 Para.	Tube Passes	4

Utilities	None
Controls	
Tolerances	
Comments & Drawings	

LIQFLAH

Identification	Item	Gas-fired Heater	**Date**	23-Apr-19
	Item No.	S-E101	**By**	TD, KK, JP
	No. Required	1		

Function To heat fuel product for efficient separation of diesel and gasoline with a flash drum

Operation Semi-Continuous

Property Variables	**Inlet**	**Outlet**
Temperature (°C)	50.4	120.0
Pressure (psi)	362.6	362.6
Composition		
TOTAL (lb/hr)	27,266	27,266
CO	--	--
CO_2	1,371	1,371
H_2	4.0	4.0
Water	17,191	17,191
CH_4	--	--
C_2H_6	--	--
C_3H_8	8.8	8.8
C_4H_{10}	28	28
C_5H_{12}	77	77
C_6H_{14}	191	191
C_7H_{16}	417	417
C_8H_{18}	589	589
C_9H_{20}	585	585
$C_{10}H_{22}$	596	596
$C_{11}H_{24}$	575	575
$C_{12}H_{26}$	553	553
$C_{13}H_{28}$	519	519
$C_{14}H_{30}$	486	486
$C_{15}H_{32}$	455	455
$C_{16}H_{34}$	420	420
$C_{17}H_{36}$	384	384
$C_{18}H_{38}$	361	361
$C_{19}H_{40}$	328	328
$C_{20}H_{42}$	303	303
$C_{21}H_{44}$	280	280
$C_{22}H_{46}$	216	216
$C_{23}H_{48}$	229	229
$C_{24}H_{50}$	208	208
$C_{25}H_{52}$	189	189
$C_{26}H_{54}$	171	171
$C_{27}H_{56}$	155	155
$C_{28}H_{58}$	137	137
$C_{29}H_{60}$	126	126
$C_{30}H_{62}$	113	113

Design Data

Temperature (°C)	120	Material of Construction	Cr Mo Alloy
Pressure (psi)	362.6	Orientation	N/A
Diameter (ft)	N/A	Volume (ft^3)	N/A
Height (ft)	N/A		

Utilities Fuel Gas

Controls

Tolerances

Comments & Drawings Stainless steel used for construction due to corrosion concerns

LUBEHX

Identification	Item	Shell and Tube Heat Exchanger	**Date**	23-Apr-19
	Item No.	S-X101	**By**	TD, KK, JP
	No. Required	1		

Function	To heat decanted water and hydrocarbons and cool diesel product
Operation	Continuous

Property Variables	**Shell Side**	**Tube Side**
Temperature (°C)	122-123	89.5-270
Pressure (psi)	363-356	363-358
Pressure Drop (psi)	7.25	5.08
Material of Construction	Stainless Steel	Stainless Steel
Composition		
TOTAL (lb/hr)	19,156	18
CH_4	0	4.90E-06
C_2H_6	0	3.90E-04
C_3H_8	0	1.76E-03
C_4H_{10}	0	1.04E-02
C_5H_{12}	0	2.33E-02
C_6H_{14}	0	8.97E-02
C_7H_{16}	0	7.56E-02
C_8H_{18}	0	1.70E-03
C_9H_{20}	57	3.60E-01
$C_{10}H_{22}$	0	7.10E-02
$C_{11}H_{24}$	0	6.70E-02
$C_{12}H_{26}$	0	6.50E-02
$C_{13}H_{28}$	0	6.80E-02
$C_{14}H_{30}$	0	6.60E-02
$C_{15}H_{32}$	0	1.73E+00
$C_{16}H_{34}$	0	5.93E-02
$C_{17}H_{36}$	31	2.43
$C_{18}H_{38}$	48	2.67
$C_{19}H_{40}$	71	2.65
$C_{20}H_{42}$	95	2.25
$C_{21}H_{44}$	117	1.78
$C_{22}H_{46}$	129	1.19
$C_{23}H_{48}$	140	0.84
$C_{24}H_{50}$	141	0.55
$C_{25}H_{52}$	136	0.35
$C_{26}H_{54}$	135	0.23
$C_{27}H_{56}$	127	0.16
$C_{28}H_{58}$	125	0.01
$C_{29}H_{60}$	109	0.08
$C_{30}H_{62}$	100	0.07
CO	0	0
CO_2	515	0
H_2	3.8	0
Water	17,076	0

Design Data			
Area (ft^2)	30.4	Heat Duty (BTU/hr)	4.68E+03
Shell Passes	1 Series / 1 Para.	Tube Passes	8

Utilities	None
Controls	
Tolerances	
Comments & Drawings	Tube side contains small amounts of heavy alkanes

Section 17

Equipment Cost Summary

Equipment Cost Summary

In modeling some of the larger and more prominent pieces of equipment in our process, we looked for real life equipment for pricing and output information. We searched for the highest flow rate industrial fan available and found the Backward Inclined Double Width (BIDW) Centrifugal Fan from Industrial Air Technology Corporation, with a flow rate of 280,000 CFM and a diameter of 6 feet. At this flow rate we still need 113 of these massive fans to reach our scale requirement. After successfully contacting Industrial Air Technology Corporation's sales department we were able to receive a quote for their BIDW Centrifugal Fan price of $60,000 per fan and its energy consumption of 351.2 brake horsepower (BHP) or 400 actual horsepower (AHP). These estimates allowed us to proceed in our economic analysis confidently using a real world example of a unit that could very feasibly be used in our process.[40]

We similarly searched for the highest output electrolyzer and found the McPhy Augmented McLyzer 800-30, which generates 800 m^3/h of H_2 with an efficiency of 78.8%, meaning a power consumption 4.5 kWh/m^3 H_2.[41] Even at this high output our process still requires 135 of these huge electrolyzers to produce the requisite hydrogen. Some companies offer larger output options up to about 4,000 m^3/h upon request, but none have answered us and this output is still well below our need. Many of these electrolyzer systems are modular, so it seems that an electrolyzer array of our required size is possible, but very far from profitable.

McPhy has also not answered our inquiries about the price of their Augmented McLyzer 800-30, so we have estimated its cost from studies on the electrolyzer industry. A recent report on the current status and future projections of electrolysis technologies predicted current

electrolyzer prices at about $783.20/kW, estimating the size of an electrolyzer from its electricity consumption and therefore by its hydrogen output.[42] At this price, an array of 135 McPhy Augmented McLyzer 800-30's would cost about $378.5 million, or $2.8 million per electrolyzer.

The main operating cost of electrolyzers is their huge electricity consumption. The McPhy Augmented McLyzer 800-30 consumes 4.5 kWh/m^3 H_2, on the higher end of efficiency for electrolyzers. The electricity required to power our electrolyzer array would cost $812,000/day, or $406/bbl. This cost far outweighs our revenue, so the energy required to power our electrolyzers must come from another source.[41]

We obtain the energy for our electrolyzers from solar panels, shifting the daily cost of purchasing electricity onto the investment of buying solar panels. The national average price of solar panels is $3.05/W, and our planned site location of Texas has a policy to pay for 30% of solar panel installation costs. Just the carbon capture fans and electrolyzer array require about 484 MW of power. Assuming a bulk purchase price below the average of $2.40/W, buying enough solar panels to meet our energy requirement would cost $812 million.[43]

Section 18

Fixed Capital Investment Summary

Fixed Capital Investment Summary

Our capital investment is one of the largest obstacles keeping the AIR TO FUELS™ process unprofitable. We have shifted many profitability limiting operating costs onto our total permanent investment in an effort to show that while the process is not currently profitable it could be in the future, although there are still challenges and inefficiencies in the operating costs to overcome.

The majority of our fixed capital investment is placed into the green components of our process: the carbon capture and hydrogen generation systems. A carbon capture system on the 2000 bbl/day scale of our project does not yet exist, so we were forced to make certain assumptions and take certain liberties in modeling it. We approximated our carbon capture system as a large cooling tower connected to an array of high capacity fans. This system is akin to a cooling tower in that it aims to contact a liquid with air, but our goal is opposite that of normal cooling towers in seeking to move huge amounts of air against relatively much less absorbing solution. Still, the cooling tower and fan array model provides a good cost estimate of $560,000 for the cooling tower, then $6.8 million for the array of 113 BIDW centrifugal fans.[40]

The AIR TO FUELS™ process hydrogen generation system is the real bottleneck of our total permanent investment. After exploring multiple options for hydrogen generation including direct purchase and steam methane reforming, we decided on electrolysis as the most green option with the best prospects for the future. However, our project requires a huge amount of hydrogen, and to generate this requires both a huge number of electrolyzers and a lot of electricity. To produce our requisite 115,000 m^3/h of H_2 requires 135 of the highest output (800

m^3/h H_2), highest efficiency (4.5 kWh/m^3 H_2) electrolyzers we've found, the McPhy Augmented McLyzer 800-30.[41] Based on a recent report on the current status and future projections of electrolysis technologies, electrolyzers cost about $7,83.20/kW, using electricity consumption to estimate the size of an electrolyzer.[42] At this price, our electrolyzer array costs almost $378.5 million. Additionally, purchasing the almost 484 MW of electricity for this much hydrogen generation would cost hundreds of thousand of dollars per day, so we must shift this high daily cost onto our capital investment through solar panels. Enough solar panels to provide 484 MW of electricity cost a colossal $812 million.[43] This solar panel cost is our single greatest capital investment. Our hope is, and it seems very likely, that both solar panels and electrolyzer technologies will continue to develop in future years to be both more energy efficient and cheaper so that the AIR TO FUELS™ process could one day be profitable.

After the costs of our carbon capture fans and cooling tower, electrolyzer array, and solar panels, the remainder of our total permanent investment is comprised of the bulk of the process' fabricated machinery and catalysts. The costs of all of our reactors, heat exchangers, fired heaters, compressors, storage tanks, pumps, distillation columns, flash blocks, catalysts, and solids handling units sums to about $300 million. We considered the cost of our initial absorbing solution salts as a fixed cost like the rest of our catalysts. For storage tanks, we accounted for solid $CaCO_3$ storage, in case we wish to simply bury the captured carbon, and Fischer-Tropsch reaction product storage to ensure steady product supply. The cost of all this process machinery is already enough to finance a full chemical processing plant, and the huge additional costs of our massive carbon capture and hydrogen generation systems push the investment cost far above the actual scale of our plant.

The AIR TO FUELS™ process' $2.2 billion TPI is its largest economic obstacle. At the current price of oil, our TPI would need to drop 82% to around $396 million and our largest operating costs of cooling water and salt replenishment would need to drop from improved efficiency to push our IRR positive. Projecting our project economics past the very conservative estimate of 10 years and including salvage costs for some of our most expensive equipment, like our $812 million solar panels array, would also significantly improve our economic prospects, but such measures are not prudent for a conservative economic analysis. The confines placed on our project by its green focus force us to invest in such clean technologies as electrolyzers and solar panels that are still in development compared to their non-renewable counterparts. We would hope that this type of investment would greatly help these technologies grow into industry standards, but for now the future profitability of the AIR TO FUELS™ process is largely dictated by the development of solar panel, electrolyzer, and carbon capture technologies.

Section 19

Operating Cost – Cost of Manufacture

Operating Cost - Cost of Manufacture

The green mission of the AIR TO FUELS™ process has given our project many constraints to work around and many difficult economic choices to make. At crucial points in our process design we had to choose to place costs either in our operating costs and close our daily profitability margin or in our total permanent investment and hope for at least daily profitability. Due to the structure and size of our project's costs, we often chose to turn daily costs into investments. Because of this, our operating costs only cover some sections of our process, while others are paid up front through permanent investments.

Unlike most processes to produce oil, our raw materials, air and water, are virtually free, incurring a small cost of only $0.66/bbl of green crude synthetic oil. Our process also requires a hydrogen feed stream that instead of purchasing either directly or in natural gas we generate on site through electrolysis. This is a large example of shifting the operating cost of raw materials onto our capital investment, here in the form of electrolyzers. This cheap starting material cost, however, is more than made up for in other operating costs. We modeled our CO_2 scrubbing solution to purge 5% of the absorbing solution per day, meaning that we must purchase and replace that mass of KOH and $Ca(OH)_2$ each day. In our ASPEN models, this quantity of salts costs $86.74/bbl, nearing our revenue of $106/bbl including byproducts. Other non-ASPEN models estimate the cost of salt replacement to be only cents, but this is difficult to model as carbon capture systems of this scale have not yet been developed. Using the ASPEN estimate for our final model, our profitability margin is already thin and is further closed with the inclusion of utility costs.

The utilities required by the AIR TO FUELS™ process are electricity, cooling water, chilled water, and refrigeration of -150ºF (ethylene) and -30ºF (ammonia), 30 psig and 150 psig steam, and fuel gas. The most expensive utility by far is electricity. The majority of our electricity demand comes from our electrolyzer array producing 107,000 m^3/h of H_2, and the operating cost of this utility alone is $812,000/day or $406/bbl. However, we circumvent this daily cost, which again surpasses the daily revenue of our product, by investing in solar panels to satisfy our electricity utility requirement. The benefit of eliminating this operating cost comes at the expense of our total permanent investment.

The remainder of our utilities are cooling water, chilled water, and refrigeration of -150ºF (ethylene) and -30ºF (ammonia), 30 psig and 150 psig steam, and fuel gas. Altogether these cost about $55.76/bbl, which seems a much more reasonable unit operating cost compared to our product unit price of $106/bbl including byproducts, but together with the ASPEN estimated salt costs still puts our daily profits in the red. We are able to cover a portion of our fuel gas utility requirement, which is about 94 MMBTU/hr, by burning the excess hydrogen and light alkane products of our FT reaction. These remaining gases net us 71 MMBTU/hr, reducing our fuel gas requirement to only 23 MMBTU/hr.

Section 19.1: Fixed Costs

The majority of our fixed costs are calculated using the default values and multipliers suggested in *Product and Process Design Principles*.[33] These costs comprise the majority of our fixed costs at about $280 million. The remaining variable in our fixed costs is the number of operators our plant requires. To determine this, we divided the AIR

TO FUELS™ process into the following sections, with the number of operators needed in each section determined by the type of processes it encompasses:

1. CO_2 Capture - 2 operator
2. CO_2 Pellet Release - 3 operators
3. Water Electrolysis - 1 operator
4. Water Gas Shift (WGS) - 1 operator
5. Fischer-Tropsch Reaction (FT) - 1 operator
6. Product Separation (Distillation) - 2 operators

Total number of operators: 10

Since the process is semi-large scale at 2000 bbl or about 300 US tons of crude oil per day, we multiplied this number of operators by 1.3 to conservatively conclude that the process requires 13 operators. We estimate that our operators would be paid at a rate of $40/hr and assume a schedule of 5 shifts.

Section 20

Other Important Considerations

Other Important Considerations

Section 20.1 : Environmental Concerns

It is very important to keep in mind one of the primary purposes of the AIR TO FUELS™ process is to be as environmentally friendly as is possible while producing the requisite 2000 bbl/day of fuel. The synthetic fuel produced in this process is produced using carbon dioxide captured from the ambient air and the methods of production utilized in the AIR TO FUELS™ process do not produce greenhouse gases. For example, as opposed to typical hydrogen production methods that produce carbon dioxide, the AIR TO FUELS™ process uses the electrolysis of water, which produces only oxygen gas as a byproduct as opposed to carbon dioxide. Also of note is the use of solar panels to provide electricity for the plant. Solar panels are of course, one the most environmentally friendly ways to power a plant of such an enormous scale.

Possibilities for integration with other chemical process plants also allow for increased environmental consciousness. Typically, gases like hydrogen and methane are not useful when produced as by-product and are flared by the producers, which naturally releases carbon dioxide into the atmosphere. If the AIR TO FUELS™ plant purchases these by-product gases (as large amounts of hydrogen are required in all cases, and even methane is useful if steam methane reforming is chosen as the method of production for syngas) it eliminates this source of greenhouse gases and cuts costs associated with water electrolysis, which is a situation ideal for both plants.

It is also important to recognize that the fuels produced by the AIR TO FUELS™ process are not environmentally friendly, they are simply the hydrocarbons that are typically used in fuel. The combustion of these alkanes does produce more carbon dioxide, which renders the amount of carbon dioxide used to produce said fuel essentially moot. Thusly, the AIR TO FUELS™ process is not carbon negative, but carbon neutral.

Efforts have been taken to preserve this carbon neutrality by working to ensure that efficiency within the process is as high as is possible by utilizing recycle streams to minimize the amount of carbon dioxide left at the end of the process. In addition, as opposed to making use of the aforementioned flares to dispose of the light alkanes produced by the Fischer-Tropsch reactor, they will instead be used as heat sources within the process.

Ignoring the carbon emissions incurred by our product, it is interesting to compare our carbon removal capabilities to the current scale of emissions and global limits. Current climate scientists and activists hope to keep global warming under 2ºC maximum compared to pre-industrial (1850) global temperatures, but ideally under 1.5ºC. Estimates vary widely in how much carbon dioxide they predict we can emit before global temperatures rise above these levels, but many estimate this remaining carbon budget to be near 200 $GtCO_2$ before we hit the 1.5C limit.[44] Human activity, including both industrial operations and land usage, releases about 10 $GtCO_2$ per year into our atmosphere.[45] To compare, our process removes a significant 0.365 $GtCO_2$ per year from our atmosphere. At this rate, the world would require about 28 of our plants, or one plant on the scale of 56,000 bbl/day (which is not unrealistic in the oil industry) to meet our current carbon emissions. Beyond this it would take our plant 550 years to remove the remaining carbon budget of 200 $GtCO_2$. Clearly, our one AIR TO FUELS™ plant is not going to solve global warming on its own, but it would certainly recapture a significant 3.56% of our

current carbon emissions and help to raise our carbon budget, buying us more time to change our society's dependence on non-renewable energy.

Section 20.2: Safety Concerns

The main safety concerns associated with the AIR TO FUELS™ process are twofold: asphyxiation from gas leaks or explosion. The plant involves the transport of large amounts of gas that if allowed to pool in one location, would easily asphyxiate a plant operator as the gases are colorless and odorless (nitrogen, carbon dioxide, etc.). Of particular note is syngas, which contains large amounts of carbon monoxide, a colorless and odorless gas that is also extremely toxic. Care must be taken to make sure that no more than trace amounts of carbon monoxide are allowed to escape the process, as even ppm amounts can be fatal.

It is also important to be wary of hydrogen gas. The water gas shift reaction runs with a large excess of hydrogen gas, and as such, it is carried through the process. If this gas is allowed to build up and ignites, a dangerous explosion will result. Hydrogen fires are also particularly dangerous because they can occur at extremely varied concentrations of hydrogen in air (anywhere from 4% to 75% by mole). This compounds with the fact that hydrogen fires do not radiate large amounts of heat and are a pale blue in color, meaning that oftentimes, it is nearly impossible to notice that there is a hydrogen fire nearby until one is standing in the midst of one. Due to this, additional precautions must be taken to ensure that hydrogen gas does not build up and become a hazard.

Included in the Appendix section of this report are the safety data sheets for each of the compounds that are utilized in the AIR TO FUELS™ process.

Section 20.3: Location

After consideration of several important factors, it was determined that the most ideal location of the AIR TO FUELS™ plant is in the south of Texas, near the city of Corpus Christi. Most important in terms of location choice is the economic value of the area and climate of the area. Land in Texas is both relatively cheap and plentiful, which is necessary for a plant of this size, especially as it will include over 100 acres of solar panels (it is also important to note that the south of Texas is quite a sunny area). Naturally, the plant itself will also take up a large amount of space apart from the solar panel field, so it is necessary to build in a location that is not built to capacity.[43] This restriction rules out areas like the Northeast and the Pacific Coast, which are also not ideal for the humidity requirement. It is ideal for the air around the plant to be humid most of the air for equilibrium to favor water remaining in the process and not evaporating into the ambient air. Corpus Christi has an average humidity of at least 60% for over 9 months of the year, which is ideal for this process. Humidity levels across the contiguous states can be seen in **Figure 5.**

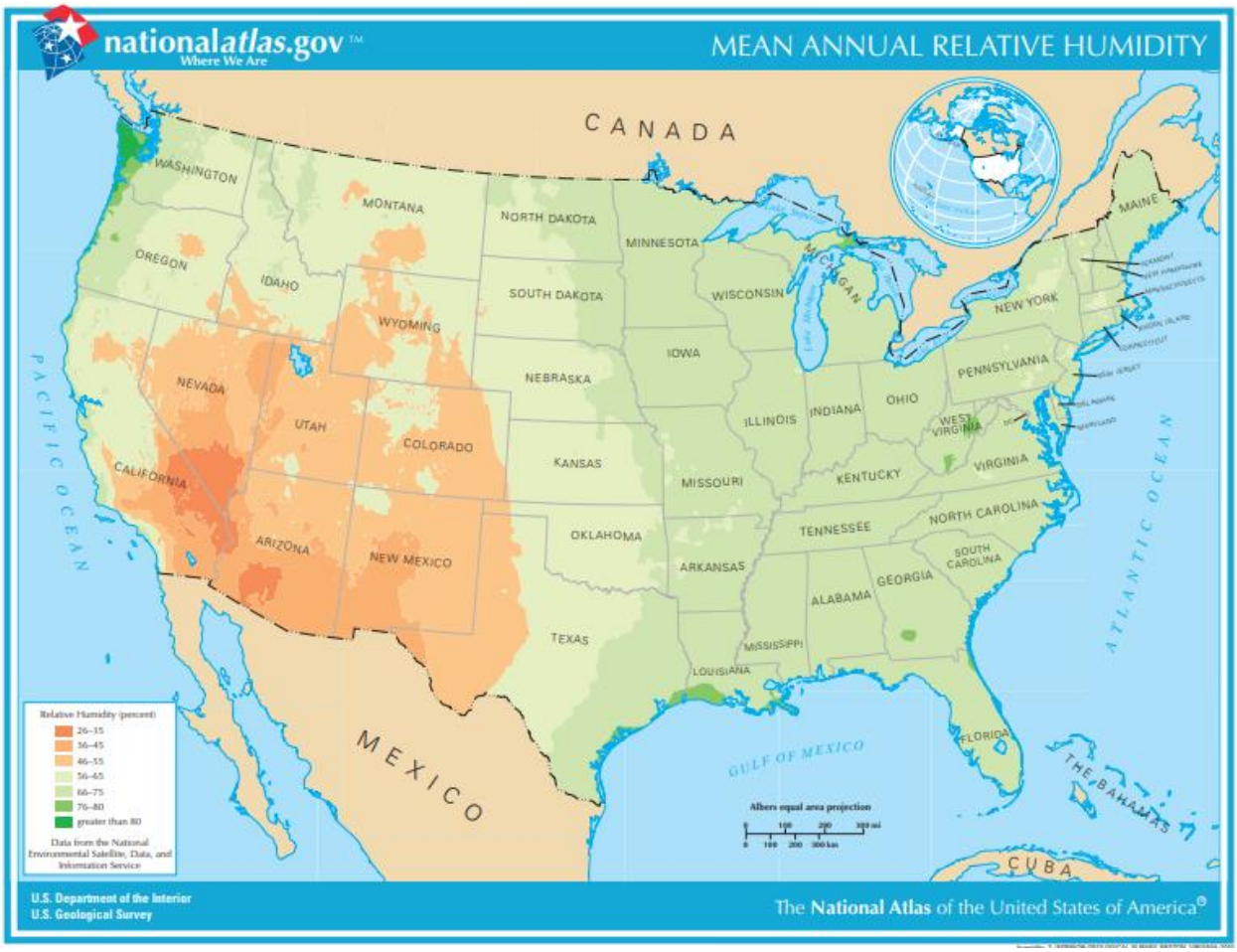


Figure 5: Average humidity across the continental United States.[46]

Texas is also ideal in regards to the credit and subsidies given for environmentally friendly processes. In an effort to increase the proportion of renewable energies (from 2,500 MW to 10,000 MW of power), the state of Texas offers subsidies to companies that operate carbon neutrally, which AIR TO FUELS™ would indeed qualify for. This subsidy would likely help to make the plant more profitable as it would work to offset the cost of operating with the more expensive renewable energy. It is also possible to make use of the Federal solar tax credit, which reimburses 30% of the purchase cost of solar panels. In the case of the AIR TO FUELS™ plant, this amounts to nearly 50 million dollars of savings due to the enormous amount of energy

needed to run the process (particularly the electrolyzers). Though other parts of the world offer similar incentives for renewable energy, the coast of Texas is also the home of many major oil refineries, allowing for a partnership between the AIR TO FUELS™ plant as the producer and the oil refinery as its consumer, which saves on shipping cost.

Section 21

Profitability Analysis – Business Case

Profitability Analysis – Business Case

The relevant approximate and rigorous profitability measures are summarized in the table below. These measures are calculated using a 5 year MACRS depreciation schedule, 23% tax rate, and projecting a 10 year project lifetime. They also assume the use of atmospheric air to obtain carbon and electrolysis and clean electricity to obtain hydrogen (more on these assumptions below).

NPV	ROI	IRR
$(2,473,897,700)	-17.17%	Negative IRR

The total permanent investment of the AIR TO FUELS™ process to capture and convert atmospheric carbon dioxide into liquid fuels is the main economic roadblock. It dwarfs all of our other costs both fixed and variable, so that even large changes in fields like the price of oil or the cost of electricity would not necessarily bring our profitability margin into the green. Still, even though the process is not profitable with the current state of relevant technologies and the oil industry, this does not mean that it will never be. The largest economic obstacles to the process are the price of oil, the current scale of electrolysis and solar panel technologies, and the concentration of carbon dioxide in our feed stream. Other smaller factors that could aid the AIR TO FUELS™ process in turning a profit include the expansion of the renewable natural gas (RNG) industry, and further development of carbon capture technologies.

Section 21.1: Products

Although our project statement suggested we sell our product as a combination of gasoline, diesel, and jet fuel, we have decided to sell it instead as crude oil. Processing crude oil into a consumer product is the mission of huge oil refineries across the world, with decades of innovation and development behind them. We have deemed it out of the scope of our project to design an oil refinery to process out Fischer-Tropsch reaction product into a consumer product, and have instead opted to sell it as a semi-refined crude oil.

The price of oil has fluctuated wildly over the past century of our society's dependence on fossil fuels. As **Figure 6** shows, the cost of a barrel of crude oil has ranged from $15 to $160 just over the past 25 years.[47] Our economic analysis assumes the current price of about $60/bbl for crude oil, increased by 20% to $72/bbl to account for the cleanness (free of heavy metals, NO_x, and SO_x) and environmental greenness of our product. Unfortunately, at our current $2.2 billion total permanent investment, there is no historical or even feasible crude oil price that would make our process profitable. However, if this investment were to drop significantly, perhaps due to technology improvements easing costs, then the historical high crude oil price of $160/bbl could make our process profitable.

Figure 6: Inflation-adjusted crude oil price per year.[47]

While this synthetic crude oil is the main product of the AIR TO FUELS™ process, we produce two sellable by-products that significantly increase our daily revenue. Because of the chemistry behind the Fischer-Tropsch polymerization reaction, we produce large amounts of light and heavy alkanes that cannot be used in our fuel and are separated out. The light alkanes we plan to burn to provide some heat to the process, and to recycle the carbon dioxide back into our carbon capture system to avoid any emissions. The heavy alkanes, hower, we hope to sell as waxes and lubricants. Paraffin waxes sell at about $1.03/kg, but out waxes like our crude oil, would be very pure and produced through an environmentally friendly process, so we hope to set a 20% premium on this price as well to sell at $1.24/kg.[48] About 26.11 kg of wax are produced

for every barrel of oil, adding about $32.38 revenue per barrel of oil, and thus increasing daily revenue by 45%.

The second by-product we produce is oxygen gas, released proportionally to hydrogen gas in electrolysis. Oxygen is sold in many forms like liquid or compressed for different purposes, and we are not sure in what form we would sell our oxygen, or if we could even make use of it somehow in the process like we do our light alkane products. Oxygen gas is not as profitable as heavy alkanes produced in Fischer-Tropsch, but it still sells at $0.003/kg. With the amount of hydrogen the process requires, we also produce 920.63 kg/bbl O_2, adding an additional $1.84/bbl to our revenue.

Section 21.2: Carbon Capture

Carbon capture technologies are still growing as society and industries refocus around the threat of climate change. Some sources claim that reducing or even ending carbon emissions would not be enough to reverse the disastrous effects of global warming, so we must actively remove carbon dioxide from the air. the AIR TO FUELS™ process aims to do just this, and to produce usable fuels from the captured carbon; however, carbon capture systems have not yet been developed on the scale of our fuel synthesis process, and many aspects of our models veer into uncharted territory.

The focus of the AIR TO FUELS™ process in its green mission is the carbon capture system, which pulls carbon dioxide from the air using an absorbing solution. the process goal of 2,000 bbl/day of oil requires us to capture 1000 metric tons of CO_2 per day. Since the concentration of CO_2 in the atmosphere is only 0.04% by volume, we have to move a massive amount of 31.5 million cubic feet per minute (CFM) of air in order to obtain the requisite amount

of carbon dioxide. In their patent, Carbon Engineering, the company on which this project is based, uses an array of fans to move air in their carbon capture system, and we intend to do something similar on a much larger scale.

We modeled the fans used in the process as Backward Inclined Double Width (BIDW) Centrifugal Fan from Industrial Air Technology Corporation, the largest capacity centrifugal fan we would find. Although there may be some larger fans, we chose to look for specifically for centrifugal fans because they are the most efficient and would save us electricity costs in one of the largest components of the process. The BIDW can move 280,000 CFM of air, run on 351.2 brake horsepower (BHP) or 400 actual horsepower (AHP), and cost at least $60,000 per fan. At this flow rate, we need 113 fans for a total of $6.8 million in purchase costs and $56,000 in daily electricity costs (assuming $.07/kWh), or $28/bbl in electricity. Selling our product at $72/bbl and even accounting for an additional $32/bbl in paraffin byproducts, $28/bbl in fan electricity costs is a large chunk out of our revenue. This and other daily electricity costs are why we are forced to generate our own electricity.[40]

The carbon capture system also requires us to contact an absorbing solution of KOH and $Ca(OH)_2$ with the air flowing through the process. On the advice of our industrial consultants, we have modeled this aspect of the carbon capture system as a cooling tower that disperses our absorbing solution to capture CO_2 instead of water to evaporate. Cooling towers are common process units in many chemical processes which reject heat from a system through the evaporative cooling of water. Common examples of cooling towers include the large hyperbolic towers seen in nuclear power plants and the small units found on the roofs of many modern buildings. Nuclear power plants use natural draft cooling towers, which diffuse hot water within the hyperbolic towers to evaporate, taking heat with it and causing the system to flow by the

relative buoyancy of hot vapor. Cooling towers found on top of many buildings are forced draft cooling towers, which use fans to force air through the dispersed hot water to reject more heat using a smaller unit.

Both of these cooling towers, and all cooling towers by design, operate best by flowing a large amount of water against a relatively smaller amount of air, and this is where the process is different. Our goal is not to evaporate as much water as possible but the opposite, to absorb as much carbon dioxide from air as possible. Our carbon capture system requires a relatively much greater flow rate of air than that of our absorbing solution, unlike cooling towers. Such a large-scale system of this type does not yet seem to exist, and this is a drawback of current carbon capture technology that we hope will gain further development in the future.

We have modeled our carbon capture system as a large natural draft cooling tower, like those at nuclear power plants, connected to our array of fans to force air through. The cooling tower can effectively disperse at least 900 L/s of our solution to absorb as much CO_2 as possible while our array of fans pushes the requisite air through. Using a resource from one of our industrial consultants, we have estimated the cost of a natural draft cooling tower at this flow rate to be about $560,000. While this exact set up of fans connected to a hyperbolic cooling tower is probably not exactly reflective of what a real-life system of this sort would look like, it allows us to model the economics of our carbon capture system with a good degree of confidence and precision.

We have accounted for the cost of KOH and $Ca(OH)_2$ in our absorbing solution, as a combination of fixed and variable costs. Our carbon capture systems requires a certain amount of these salts to be in solution at any given time in order to absorb carbon dioxide, and we economically modeled this initial charge of salts like a catalyst. We have accounted for this

initial charge of salts like a catalyst as a fixed cost of $5.4 million for 9.5 million kg of KOH and 280,000 kg of $Ca(OH)_2$. Then, we will purge 5% of the absorbing solution each day to maintain its concentration, with the cost to replace this modeled as a variable cost alongside the other operating costs. To replace 170,000 kg KOH and 117,000 kg $Ca(OH)_2$ per day costs a total of $173,480/day or $86.74/bbl. Just this cost alone significantly thins the margin between our daily revenue of $106/bbl including by-products and our daily costs. These estimates of required salt masses come from ASPEN, and are significantly higher than our previous models based on salt solubility and the stoichiometry of the absorbing reaction. Again, a carbon dioxide capture system of this scale and type has not yet been developed, so our modeling is most likely not representative of how a real-life system would behave.

The concentration of carbon dioxide in our feed stream, which we have modeled as that of atmospheric air, 0.04% by volume, is a critical number to the process in that it sets the scale of our carbon capture system. For this reason, it is important for us to consider how even slight changes in this concentration would affect the process. One option to increase the incoming concentration of CO_2 is to place the process downstream of a significant CO_2 source, such as a power plant or fermentation facility. Power plants can often have effluent CO_2 concentrations of up to 6%, a 150x increase from atmospheric air. Capturing the CO_2 released by another process would greatly increase the concentration of CO_2 entering the process and significantly decrease the scale our carbon capture system. With only a slight increase in the volumetric carbon dioxide content of incoming air, the process would require fewer fans, reduced capital costs, and significantly less electricity. **Figures 7-9** show the effects of increased incoming carbon dioxide concentration on these economic factors.

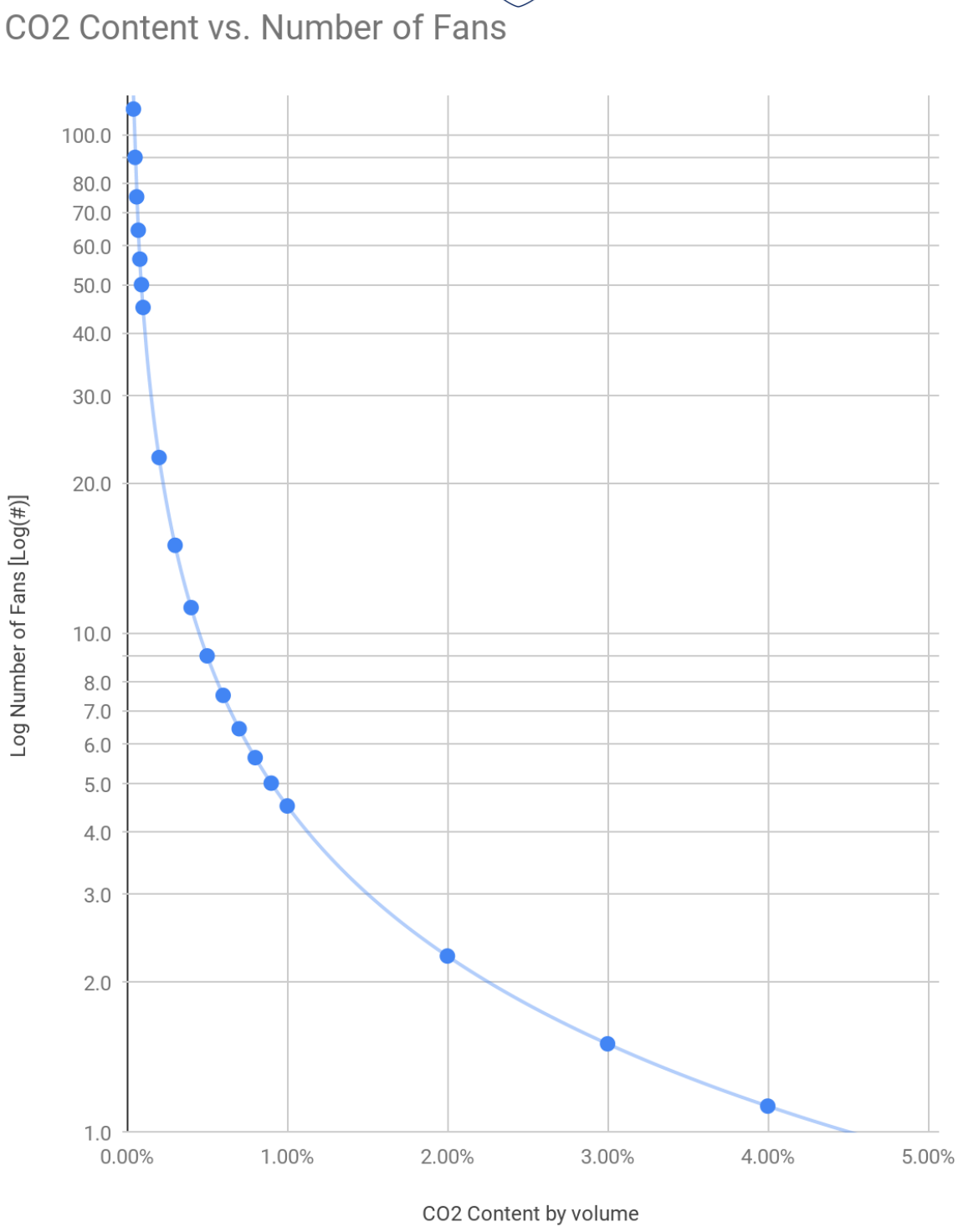


Figure 7: Graph of the required number of fans versus the CO_2 content in the air.

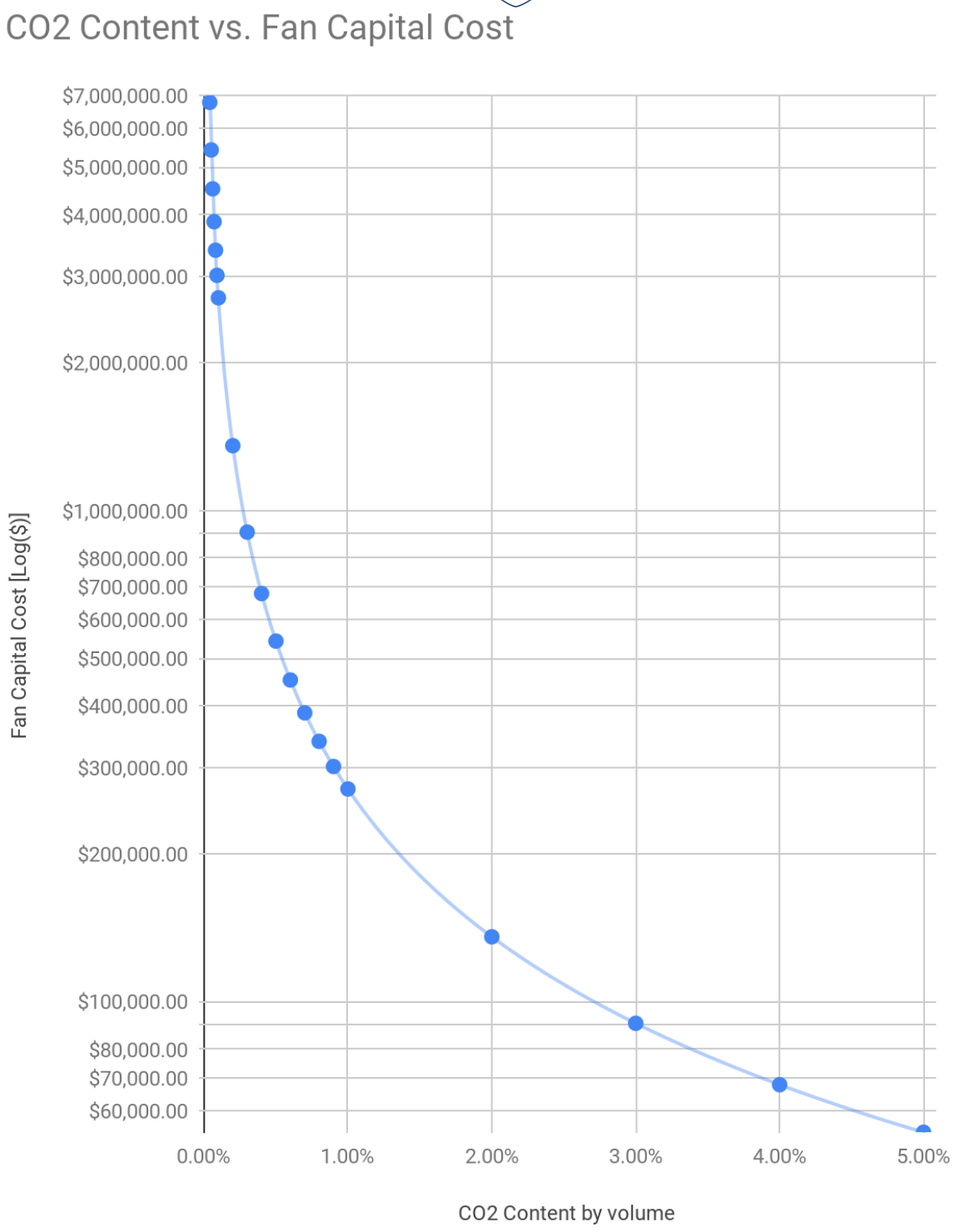


Figure 8: Capital cost of the fan bank versus atmospheric CO_2 concentration.

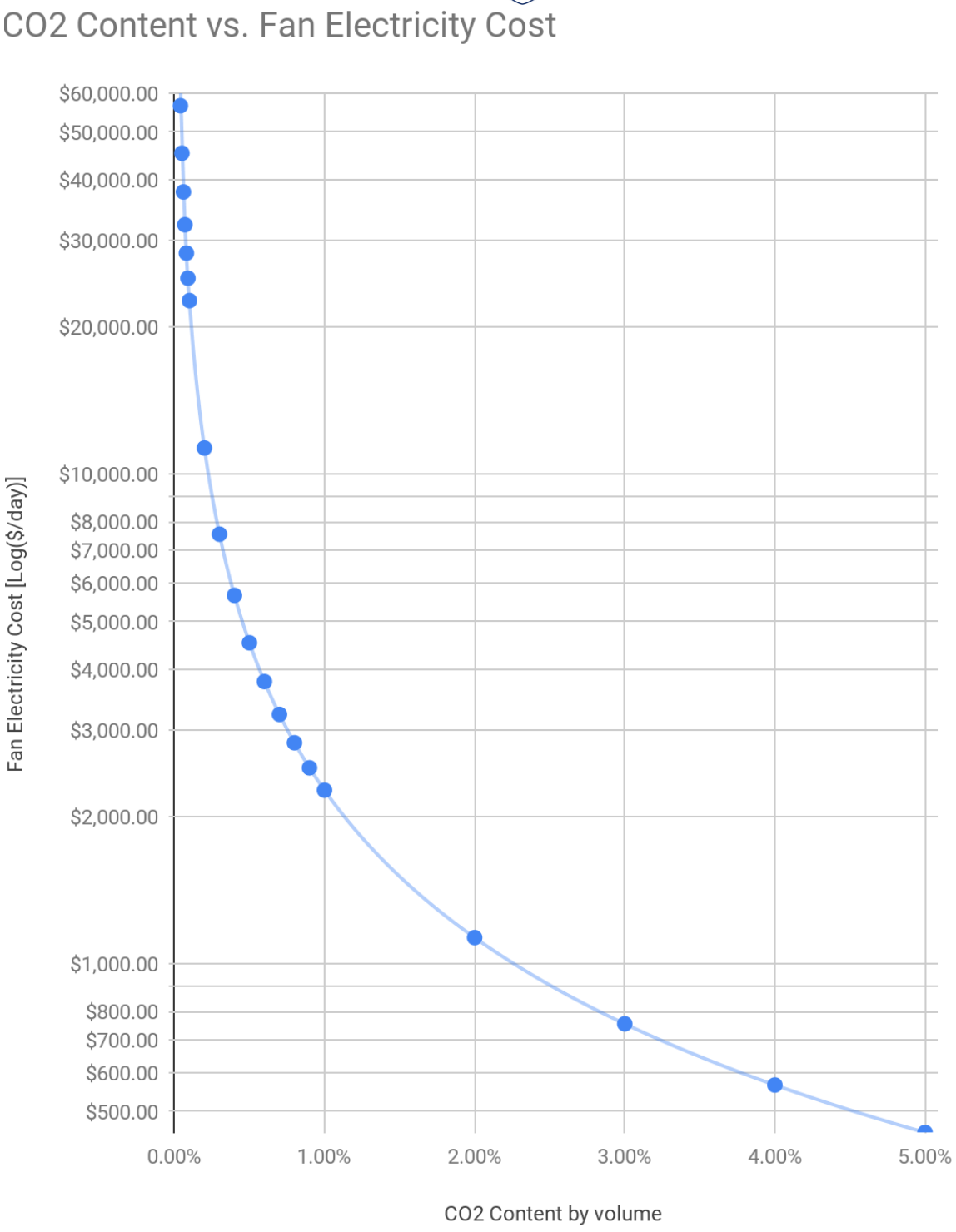


Figure 9: Graph of fan electricity cost versus atmospheric CO_2 concentration.

Section 21.3: Hydrogen Production

Our final product of liquid alkanes is composed entirely of carbon and hydrogen, and while carbon is readily available in the atmosphere, hydrogen gas must be generated or bought. Our projects assumes, as we have ultimately concluded, that we generate hydrogen for the process through water electrolysis, an environmentally clean process that's only by-product is oxygen, though there are notable alternatives. Still, electrolyzers are complex and expensive electrochemical machines, and electrolysis is still a small, mostly lab-scale technology.

The current capital cost of electrolyzers is very high, and the AIR TO FUELS™ process requires industrial amounts of hydrogen past what the electrolyzers industry can currently produce within reason. the process requires 115,000 m^3/h of H_2, but the average electrolyzer on the market produces only about 60 m^3/h. The largest model we could find, the McPhy Augmented McLyzer 800-30, produces 800 m^3/h, but even at this relatively large output we would need 135 electrolyzers available to satisfy our hydrogen need. Electrolyzers are generally modular machines, so some companies offer larger output options up to about 4,000 m^3/h upon request, but even using gargantuan systems like this we would still need 27 electrolyzers to obtain the hydrogen required to produce 2000 bbl/day of synthetic crude oil. none have answered us and this output is still well below our need.[41]

If we were to purchase enough electrolyzers to meet our need, the process would quickly become unprofitable as our total permanent investment shoots up. A recent report on the current status and future projections of electrolysis technologies predicted current electrolyzer prices at about $783.20/kW, estimating the size of an electrolyzer from its electricity consumption and therefore by its hydrogen output.[42] At this price, an array of electrolyzers like the McPhy Augmented McLyzer to satisfy our hydrogen need would cost almost $378.5 million. This is one

of the largest single fixed costs of the process. Electrolyzer prices are projected to drop anywhere from 30-50% in the next 10 years, with further cost reductions assumed. If hydrogen fuel cells, which operate on the reverse electrochemical reaction as electrolyzers, are any measure of the potential future cost of electrolyzers, then electrolyzer costs could continue to fall as low as $200/kW.[49] This would drop the capital cost of the electrolyzers required for the process to only $97 million, lightening their effect on our total permanent investment and greatly increasing the economic prospect of the process.

Beyond the purchasing cost, electrolyzers require a huge amount of electricity, so much that it is completely infeasible for us to buy the electricity and hope to turn any profit. Based only on the thermodynamics of water electrolysis, even at 100% efficiency splitting water requires 260 kJ/mol H_2, which would incur an electricity cost of $319.98/bbl. This cost far outweighs the selling price of our crude oil, even with the green markup and the added revenue of selling paraffins. The cost of regular crude oil would have to an unprecedented price of over $200/bbl, not even accounting for the possible added cost of buying renewably produced electricity, for purchasing electrolysis electricity to be a viable option for the process, so we must source our electricity another way.

The alternative to buying electricity for our electrolyzers, and what our project statement suggests, is to use solar panels to generate our electricity. The national average price of solar panels is $3.05/W, and our planned site location of Texas has a policy to pay for 30% of solar panel installation costs to increase the renewable energy output of the state. Using solar panels to provide the electricity needed for electrolysis would entirely shift the steep daily electricity costs to capital costs and ensure that our energy is clean. However, just the electrolyzers and carbon capture fans required in the process consume almost 484 MW of power. Even with the Texas

subsidy and assuming a bulk solar panel cost of $2.40/W, the quantity of solar panels needed to provide that much energy would cost upwards of $812 million dollars, multiplying our already high capital costs and sinking our profitability. Still, to use electrolyzers to cleanly produce hydrogen for the process we must use solar panels. Like electrolyzers, the solar panel industry is expanding quickly, and both purchase costs may be reduced and energy capturing efficiencies increased in the future. While our project is not profitable today, it may be sometime in the future, when the need to remove carbon dioxide from our atmosphere is even more pressing.[43]

Section 21.4: Hydrogen Alternatives

An obvious option to obtain our requisite hydrogen is to simply buy it, but this opens up new obstacles. First off, we would need the hydrogen to come from a green source like electrolysis or organic decomposition, not steam methane reforming (SMR). As previously noted, most industrial hydrogen comes from SMR, so this could be difficult. Still if we were to buy hydrogen produced by electrolysis, we would further need to assure that the electricity used in electrolysis came from a clean source, which could be difficult to confirm. We received a price quote from Nel Hydrogen, a company based out of Europe that uses electrolysis to produce hydrogen, of €2,000/m^3 H_2. Even if we could determine that a company like Nel Hydrogen used clean electricity for their electrolysis, this price of hydrogen would cost us over $100,000/bbl. Online sources estimate the price of hydrogen from an SMR pipeline to be around $5/kg, which would still cost the process almost $600/kg.[50] At this price, even without maintaining our carbon neutral footprint, purchasing hydrogen is clearly not an option for us.

The expansion of the electrolyzer industry has largely been in response to the current standard for hydrogen production, steam methane reforming (SMR). SMR releases hydrogen

from natural gas, but it produces by-products of carbon monoxide and dioxide that further pollute the atmosphere, and its raw materials come from non-renewable sources. Still, renewable sources of natural gas do exist, and the process uses carbon dioxide as a feed stream, so we have explored the option of using SMR to produce hydrogen.

Since the process can recycle the by-products of SMR, the issue with it is the fossil fuel feed stream of natural gas. The solution is renewable natural gas (RNG), which is chemically equivalent to natural gas extracted from the ground but produced by the decomposition or fermentation of organic matter in landfills or bioprocessing plants. With RNG as the feed stream instead of natural gas, SMR could be used to cleanly produce hydrogen, with the carbon dioxide byproduct being recycled into our carbon capture system to avoid pollution. Although the design of a full SMR plant to process RNG is out of the scope of our project, it is a worthwhile exploration since SMR is so well established as the norm for hydrogen production. Interpolating from a study on the costs of SMR plants, the total capital cost of such a plant to provide hydrogen for the process would be in the ballpark of $50-100 million.[51] This is already a fraction of the cost of electrolyzers alongside solar panels. The main variable cost of such a plant would be its RNG feed stream, incurring about $136.55/bbl, adjusted with the same 1.2x green premium as our product. This daily cost once again outweighs our daily revenue of synthetic crude oil product and by-products. For this option to be viable, the price of crude oil would have to increase to about $80/bbl. This price is not unprecedented in the tumultuous history of the oil industry as shown in **Figure 6**, but the total permanent investment of a full SMR plant, while less than our current hydrogen alternative of electrolyzers and solar panels, may still make this option ultimately unprofitable.

Another pitfall of this alternative, however, is the availability of RNG. Like many of the technologies involved in the process, the market for RNG is still growing and may not have the capacity to supply the process' massive demand for hydrogen. Additionally, if we use SMR then we would need to recycle the carbon dioxide by-product to maintain our green promise. Recycling this quantity of carbon dioxide, about 920,000 kg/day, would saturate our carbon capture system process with carbon dioxide, possibly reducing the amount of carbon dioxide we're able to sequester from the atmosphere and actually making the process less environmentally friendly. While RNG and SMR are great options to explore and may even be economically viable under the right oil market, it may be both more profitable and greener to wait for the development of electrolyzers, solar panels, and better carbon capture technologies.

Section 22

Conclusions and Recommendations

Conclusions and Recommendations

Despite the great interest in carbon capture technology and the great boons it could potentially have for the environment, currently there is no choice but to recommended that Carbon Engineering choose not to build a plant of this scope in this design. This decision was reached largely on the basis of the profitability analysis of the plant, as well as the current market for "green" fuels. Assuming reasonable circumstances for increases in price due to the higher purity of the fuel products, a negative NPV of more than 2 billion dollars, with a return on investment of approximately -17.17%. Clearly, such dismal economic predictions would not inspire confidence in possible investors.

Though there are numerous reasons for the lack of profitability of the AIR TO FUELS™ process (including high utility costs, extremely high capital cost, etc.), it is not impossible to see this technology seeing more use in the coming years. For example, circumstances like an increase in the price of oil per barrel or an increase in the demand for renewable energy could considerably increase the viability of Carbon Engineering's proposal. Perhaps the most intriguing possibility is the reentry of the United States into the Paris Accord, an pledge between 185 nations worldwide to reduce the emission of greenhouse gases in an effort to keep the increasing temperature of the globe in check. With these restrictions in place, a company that provides the fuel that America needs to function without any emissions would be particularly attractive and may be heavily subsidized by the federal government. It would also be beneficial to work to increase the efficiency of the process. Currently, only 75% of the carbon dioxide contained in air can be successfully removed with the scrubbing operation - increasing this

number will result in greater amounts of fuel produced. There may also be opportunities for optimization of the remaining parts of the process in an effort to cut the enormous utility costs.

Despite its poor economic viability, the AIR TO FUELS™ process remains extremely intriguing due to the potential boons to society if it is ever proven to be realistic. Thusly, barring any drastic changes to the current political and economic state of the world, further research is recommended to reduce costs before any action is taken to make an AIR TO FUELS™ plant of such a large scale a reality.

Section 23

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Section 24

Bibliography

Bibliography

[1] International Energy Agency. “Oil Market Reports.” https://www.iea.org/oilmarketreport/omrpublic/

[2] Fahim, M. A., Al-Sahhaf, T. A., Elkilani, A. S., (2010). *Fundamentals of Petroleum Refining*. Oxford, UK: Elsevier.

[3] "Toxic Substances Portal - Gasoline, Automotive." Centers for Disease Control and Prevention. April 08, 2019. Accessed April 10, 2019. https://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=468&tid=83.

[4] Bacha, John et. al.. *Diesel Fuels Technical Review*. Technical paper. Chevron Global Marketing.

[5] Davidson, Carolyn, Emily Newes, Amy Schwab, and Laura Vimmerstedt. *An Overview of Aviation Fuels Markets for Biofuels Stakeholders*. Technical paper no. NREL/TP-6A20-60254. National Renewable Energy Laboratory.

[6] "Avgas." Shell Global. Accessed April 06, 2019. https://www.shell.com/business-customers/aviation/aviation-fuel/avgas.html

[7] Dodaro, J. (2015, December 11). *Fischer-Tropsch Process*. Retrieved from http://large.stanford.edu/courses/2015/ph240/dodaro1/

[8] Climeworks AG. http://www.climeworks.com/our-customers/.

[9] Gebald, C., Repond, N., & Wurzbacher, A. (2017). Steam Assisted Vacuum Desorption Process for Carbon Dioxide Capture. *U.S. Patent Application No. 2017/0203249(A1)*. Washington, DC: U.S. Patent and Trademark Office.

[10] Gebald, C., Meier, W., Repond, N., Rüesch, T., & Wurzbacher, J. A. (2019). Direct Air Capture Device. *U.S. Patent No. 10232305.* Washington, DC: U.S. Patent and Trademark Office.

[11] Spiteri, A., Gutknecht, V., Wurzbacher, J. A., & Gebald, C. (2018) Methods for the Removal of CO2 from Atmospheric Air or Other CO2-Containing Gas in order to Achieve CO2 Emissions Reductions or Negative CO2 Emissions. *International Publication Number WO2018/099709(A1)*. Geneva, Switzerland: World Intellectual Property Organization.

[12] Carbon Recycling International, Vulcanol. http://www.carbonrecycling.is/vulcanol.

[13] Shulenberger, A. M., Jonsson, F. R., Ingolfsson, O., & Tran, K. (2007). Process for Producing Liquid Fuel from Carbon Dioxide and Water. *U.S. Patent Application No. 2007/0244208(A1)*. Washington, DC: U.S. Patent and Trademark Office.

[14] Carbon Recycling International. "George Olah Plant." http://www.carbonrecycling.is/george-olah.

[15] Carbon Recycling International. "Fresme Project – From Renewable Steel Gases to Methanol." http://www.carbonrecycling.is/fresme-project.

[16] From Residual Steel Gases to Methanol. http://www.fresme.eu/.

[17] Hakka, L. E., & Ouimet, M. A. (2004). Method for Recovery of CO_2 from Gas Streams. *Canadian Patent No. 2528205*. Québec, Canada: Canadian Intellectual Property Office.

[18] Ouimet, M. A. (2007). Process for the Recovery of Carbon Dioxide from a Gas Stream. *Canadian Patent No. 2673781*. Québec, Canada: Canadian Intellectual Property Office.

[19] Shaw, D.; "Cansolv CO_2 Capture: The Value of Integration," *Energy Procedia*, **2009**, *1*, 237-246.

[20] Enexio. "Natural Draft Cooling Towers." https://www.enexio.com/cooling-solutions/wet-cooling-towers/natural-draft-cooling-towers/.

[21] Enexio. "Wet Cooling Towers." https://www.enexio.com/cooling-solutions/wet-cooling-towers/.

[22] Fans Complete Technology. "Forced Draft Cooling Towers." https://www.fansct.com/en/forced-draft-cooling-towers/.

[23] Ochieng, R.; Berrouk, A. S.; Peters, C. J.; Slagle, J.; Lyddon, L.; Krouskop, P.; "Simulation of the Benfield HiPure Process of Natural Gas Sweetening for LNG Production and Evaluation of Alternatives." Petroleum Institute, Abu Dhabi, UAE; Bryan Research & Engineering, Texas, USA.

[24] Arshad, M.; Wukovits, W.; Friedl, A.; "Simulation of CO_2 Absorption Using the System K2CO3-Piperazine," *Chemical Engineering Transactions*, **2014**, *39*, 577-582.

[25] Keith, D., Mahmoudkhani, M., Biglioi, A., Hart, B., Heidel, K., & Foniok, M. (2015). Carbon Dioxide Capture Method and Facility. U.S. Patent No. 9095813. Washington, DC: U.S. Patent and Trademark Office.

[26] Rostrup-Neilsen, J. R.; "Production of synthesis gas," *Catalysis Today*, **1993**, *18*, 305-324.

[27] Fan, M.; Abdullah, A. Z.; Bhatia, S.; "Catalytic Technology for Carbon Dioxide Reforming of Methane to Synthesis Gas," *ChemCatChem*, **2009**, *1*, 192-208.

[28] Oyama, S. T.; Hacarlioglu, P.; Gu, Y.; Lee, D.; "Dry reforming of methane has no future for hydrogen production: Comparison with steam reforming at high pressure in standard and membrane reactors," *International Journal of Hydrogen Energy*, **2012**, *37*, 10444-10450.

[29] Farrauto, R. J., Dorazio, L., & Bartholomew, C. H. (2016). Generating Hydrogen and Synthesis Gas by Catalytic Hydrocarbon Steam Reforming. In *Introduction to Catalysis and Industrial Catalytic Processes* (pp. 104-128). Hoboken, NJ: John Wiley & Sons.

[30] Ayabe, S.; Omoto, H.; Utaka, T.; Kikuchi, R.; Sasaki, K.; Teraoka, Y.; Eguchi, K.; "Catalytic autothermal reforming of methane and propane over supported metal catalysts," *Applied Catalysis A: General*, **2003**, *241*, 261-269.

[31] Pruet, R. (2004). Separation of Water from Fischer-Tropsch Products. *U.S. Patent No. 7276105*. Washington, DC: U.S. Patent and Trademark Office.

[32] Valoyi, Redeem. *Modeling Water Removal From Fischer-Tropsch Products Using Glycerol*. Masters diss., University of the Witwaterstrand, 2011.

[33] Seider, Warren D., Daniel R. Lewin, J. D. Seader, Soemantri Widagdo, Rafiqul Gani, and Ka Ming Ng. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. Fourth ed. New York: J. Wiley, 2017.

[34] LinkedIn Slide Share. "Water Gas Shift Reactor Design." https://www.slideshare.net/l16cn/water-gas-shift-reactor-design

[35] Callaghan, Caitlin A.; "Kinetics and Catalysis of the Water-Gas Shift Reaction: A Microkinetic and Graph Theoretic Approach." PhD diss., Worcester Polytechnic Institute, 2006.

[36] Luo, M.; Bao, S.; Keogh, R. S.; Sarkar, A.; Jacobs, G.; Davis, B. H.; "Fischer Tropsch Synthesis: A Comparison of Iron and Cobalt Catalysts," AIChE Fall National Meeting, 12-17 November 2006. University of Kentucky, Lexington, KY.

[37] Ohtsuka, Yasuo, Takashi Arai, Satoshi Takasaki, and Naoto Tsubouchi. "Fischer−Tropsch Synthesis with Cobalt Catalysts Supported on Mesoporous Silica for Efficient Production of Diesel Fuel Fraction." *Energy & Fuels*, **2003**, *17*, 804-809.

[38] Dry, M. E.; "Practical and Theoretical Aspects of the Catalytic Fischer-Tropsch Process," *Applied Catalysis A: General*, **1996**, *138*, 319-344.

[39] Lange, Norbert Adolph. *Lange's Handbook of Chemistry*. 1985.

[40] "BIDW - Backward Inclined Double Wide." Industrial Air Technology Corp. Accessed April 21, 2019. https://indairtech.com/products/bidw-backward-inclined-double-wide/.

[41] "Augmented McLyzer." McPhy. Accessed April 21, 2019. https://mcphy.com/en/our-products-and-solutions/electrolyzers/augmented-mclyzer/.

[42] Schmidt, O., A. Gambhir, and I. Staffell. "Future Cost and Performance of Water Electrolysis: An Expert Elicitation Study." ScienceDirect. December 28, 2017. Accessed April 21, 2019. https://www.sciencedirect.com/science/article/pii/S0360319917339435.

[43] Matasci, Sara. "Solar Panel Cost: Avg. Solar Panel Prices by State in 2019 | EnergySage." Solar News. April 09, 2019. Accessed April 21, 2019. https://news.energysage.com/how-much-does-the-average-solar-panel-installation-cost-in-the-u-s/.

[44] Hausfather, Zeke. "Analysis: How Much 'carbon Budget' Is Left to Limit Global Warming to 1.5C?" Carbon Brief. September 4, 2019. Accessed April 21, 2019. https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c.

[45] User, Super. "Global Carbon Emissions." CO2.Earth. Accessed April 21, 2019. https://www.co2.earth/global-co2-emissions.

[46] The National Atlas of the United States of America. "Printable Maps." Printable Maps - Reference. Accessed April 12, 2019. https://nationalmap.gov/small_scale/printable/climatemap.html.

[47] "Crude Oil Prices - 70 Year Historical Chart." MacroTrends. Accessed April 21, 2019. https://www.macrotrends.net/1369/crude-oil-price-history-chart.

[48] "Fully Refined Paraffin Wax Price- Iran Paraffin Wax Price." RAHA Paraffin Co. Accessed April 21, 2019. http://paraffinwaxco.com/product-detail/fully-refined-paraffin-wax-price/.

[49] Tomantschger, K., F. McClusky, and L. Oporto. "Development of Low Cost Alkaline Fuel Cells." Journal of Power Sources. August 20, 2001. Accessed April 22, 2019. https://www.sciencedirect.com/science/article/pii/0378775386800891.

[50] U.S. Natural Gas Prices. Accessed April 21, 2019. https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.

[51] "Equipment Design and Cost Estimation for Small Modular Biomass Systems, Synthesis Gas Cleanup, and Oxygen Separation Equipment; Task 1: Cost Estimates of Small Modular Systems." National Renewable Energy Laboratory, 2006, 2-1-14. doi:10.2172/882499.

Section 25

Appendices

Appendix A

Economic Evaluation Spreadsheet

General Information

Process Title: **AIR TO FUELS™**
Product: **Green Crude**
Plant Site Location: **Victoria County, Texas**
Site Factor: **1.00**
Operating Hours per Year: **8640**
Operating Days Per Year: **360**
Operating Factor: **0.9863**

Product Information

This Process will Yield

83 bbl of Green Crude per hour
2,000 bbl of Green Crude per day
720,000 bbl of Green Crude per year

Price **$72.00 /bbl**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2019	Design		0.0%		
2020	Construction	100%	0.0%		
2021	Construction	0%	0.0%		
2022	Production	0%	45.0%	20.00%	$72.00
2023	Production	0%	67.5%	32.00%	$73.44
2024	Production		90.0%	19.20%	$74.91
2025	Production		90.0%	11.52%	$76.41
2026	Production		90.0%	11.52%	$77.94
2027	Production		90.0%	5.76%	$79.49
2028	Production		90.0%		$81.08

Equipment Costs

Equipment Description		**Bare Module Cost**
BIDW Centrifugal Fans (113)	Process Machinery	$14,562,640
Cooling Tower (absorption)	Process Machinery	$1,802,402
McPhy Aug McLyzer 800-30 (135)	Process Machinery	$378,546,610
Solar Panels (115 acres, 50MW)	Process Machinery	$812,500,988
Spare Fans (10)	Spares	$1,288,729
Spare Electrolyzers (2)	Spares	$5,608,098
FT Reactor	Fabricated Equipment	$11,301,292
FT Catalyst	Catalysts	$21,011,330
High T WGS Catalyst	Catalysts	$2,284
KOH	Catalysts	$5,238,095
Ca(OH)2	Catalysts	$162,242
SCREWHX (Screw Extruder)	Fabricated Equipment	$7,375,156
Flash and Distillation		
FLUFLASH	Fabricated Equipment	$2,258,830
HTWGS Reactor	Fabricated Equipment	$481,541
AIRSEP	Fabricated Equipment	$20,233,510
FLASH1	Fabricated Equipment	$1,686,366
FLASH3	Fabricated Equipment	$852,055
FLASH4	Fabricated Equipment	$506,722
FLASHLUB	Fabricated Equipment	$754,081
DECANT1	Fabricated Equipment	$668,635
Distillation Column 1	Fabricated Equipment	$913,224
Reflux Accumulator 1	Fabricated Equipment	$702,940
Reboiler 1	Fabricated Equipment	$347,239
Distillation Pump	Fabricated Equipment	$47,748
Condenser 1	Fabricated Equipment	$9,908,898
Pumps & Compressors		
KOHPUMP	Fabricated Equipment	$24,803
CAPUMP	Fabricated Equipment	$7,781
COMP1	Fabricated Equipment	$39,114,740
COMP2	Fabricated Equipment	$38,856,458
COMP3	Fabricated Equipment	$6,719,879
FLUECOMP	Fabricated Equipment	$10,393,650
Cooling Tower (utility)	Process Machinery	$1,146,525
SMR Plant (Option, Fbm=0)	Process Machinery	
Additional Equipment		$129,743,391
Total		***$1,524,768,882***

Raw Materials

	Raw Material:	Unit:	Required Ratio:		Cost of Raw Material:	
1	Air (CO2)	ft^3	22758359	ft^3 per bbl of Green Crude	$0.000E+00	per ft^3
2	Electrolysis Water	gal	273.28	gal per bbl of Green Crude	$0.00	per gal
3	Carbon Capture Water	gal	552.74	gal per bbl of Green Crude	$0.00	per gal
4	KOH	kg	84.391837	kg per bbl of Green Crude	$0.80	per kg
5	Ca(OH)2	kg	58.270364	kg per bbl of Green Crude	$0.33	per kg

Total Weighted Average: $87.404 per bbl of Green Crude

Byproducts

	Byproduct:	Unit:	Ratio to Product		Byproduct Selling Price	
1	Lubricants (Heavy Alks)	kg	26.110578	kg per bbl of Green Crude	$1.240	per kg
2	Oxygen	kg	920.63	kg per bbl of Green Crude	$2.000E-03	per kg

Total Weighted Average: $34.218 per bbl of Green Crude

Utilities

	Utility:	Unit:	Required Ratio		Utility Cost	
1	Cooling Water	gal	73.04	gal per bbl of Green Crude	$1.000E-04	per gal
2	Chilled Water	GJ	9.9468568	GJ per bbl of Green Crude	$5.000	per GJ
3	-30F Refrig (ammonia)	GJ	0.0843386	GJ per bbl of Green Crude	$13.170	per GJ
4	-150F Refrig (ethylene)	GJ	0.080965	GJ per bbl of Green Crude	$33.200	per GJ
5	150psi Steam	lb	88.812082	lb per bbl of Green Crude	$7.000E-03	per lb
6	30psi Steam	lb	52.575251	lb per bbl of Green Crude	$5.000E-03	per lb
7	Fuel Gas	SCF	266.24031	SCF per bbl of Green Crude	$0.01	per SCF
8	Electricity	kWh	0	kWh per bbl of Green Crude	$0.07	per kWh

Total Weighted Average: $55.756 per bbl of Green Crude

Variable Costs

General Expenses:

Selling / Transfer Expenses:	**3.00% of Sales**
Direct Research:	**4.80% of Sales**
Allocated Research:	**0.50% of Sales**
Administrative Expense:	**2.00% of Sales**
Management Incentive Compensation:	**1.25% of Sales**

Working Capital

Accounts Receivable	a	**30**	**Days**
Cash Reserves (excluding Raw Materials)	a	**30**	**Days**
Accounts Payable	a	**30**	**Days**
Green Crude Inventory	a	**4**	**Days**
Raw Materials	a	**2**	**Days**

Total Permanent Investment

Cost of Site Preparations:	**5.00%**	**of Total Bare Module Costs**
Cost of Service Facilities:	**5.00%**	**of Total Bare Module Costs**
Allocated Costs for utility plants and related facilities:	**$0**	
Cost of Contingencies and Contractor Fees:	**18.00%**	**of Direct Permanent Investment**
Cost of Land:	**2.00%**	**of Total Depreciable Capital**
Cost of Royalties:	**$0**	
Cost of Plant Start-Up:	**10.00%**	**of Total Depreciable Capital**

Fixed Costs

Operations

Operators per Shift:	**13**	**(assuming 5 shifts)**
Direct Wages and Benefits:	**$40**	**/operator hour**
Direct Salaries and Benefits:	**15%**	**of Direct Wages and Benefits**
Operating Supplies and Services:	**6%**	**of Direct Wages and Benefits**
Technical Assistance to Manufacturing:	**$12,000.00**	**per year, for each Operator per Shift**
Control Laboratory:	**$13,000.00**	**per year, for each Operator per Shift**

Maintenance

Wages and Benefits:	**4.50%**	**of Total Depreciable Capital**
Salaries and Benefits:	**25%**	**of Maintenance Wages and Benefits**
Materials and Services:	**100%**	**of Maintenance Wages and Benefits**
Maintenance Overhead:	**5%**	**of Maintenance Wages and Benefits**

Operating Overhead

General Plant Overhead:	**7.10%**	**of Maintenance and Operations Wages and Benefits**
Mechanical Department Services:	**2.40%**	**of Maintenance and Operations Wages and Benefits**
Employee Relations Department:	**5.90%**	**of Maintenance and Operations Wages and Benefits**
Business Services:	**7.40%**	**of Maintenance and Operations Wages and Benefits**

Property Taxes and Insurance

Property Taxes and Insurance:	**2%**	**of Total Depreciable Capital**

Straight Line Depreciation

Direct Plant:	8.00%	**of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities**
Allocated Plant:	6.00%	**of 1.18 times the Allocated Costs for Utility Plants and Related Facilities**

Other Annual Expenses

Rental Fees (Office and Laboratory Space):	**$250,000**
Licensing Fees:	**$50,000**
Miscellaneous:	**$10,000**

Depletion Allowance

Annual Depletion Allowance:	**$0**

Variable Cost Summary

Variable Costs at 100% Capacity:

General Expenses

Selling / Transfer Expenses:		$	1,555,200
Direct Research:		$	2,488,320
Allocated Research:		$	259,200
Administrative Expense:		$	1,036,800
Management Incentive Compensation:		$	648,000
Total General Expenses		$	5,987,520
Raw Materials	$87.403506 per bbl of Green Crude		$62,930,524
Byproducts	$34.218377 per bbl of Green Crude		($24,637,231)
Utilities	$55.756127 per bbl of Green Crude		$40,144,412
Total Variable Costs		**$**	**84,425,224**

Fixed Cost Summary

Operations

Direct Wages and Benefits	$	5,408,000
Direct Salaries and Benefits	$	811,200
Operating Supplies and Services	$	324,480
Technical Assistance to Manufacturing	$	780,000
Control Laboratory	$	845,000
Total Operations	**$**	**8,168,680**

Maintenance

Wages and Benefits	$	89,061,750
Salaries and Benefits	$	22,265,438
Materials and Services	$	89,061,750
Maintenance Overhead	$	4,453,088
Total Maintenance	**$**	**204,842,026**

Operating Overhead

General Plant Overhead:	$	8,345,794
Mechanical Department Services:	$	2,821,113
Employee Relations Department:	$	6,935,237
Business Services:	$	8,698,433
Total Operating Overhead	**$**	**26,800,576**

Property Taxes and Insurance

Property Taxes and Insurance:	$	39,583,000

Other Annual Expenses

Rental Fees (Office and Laboratory Space):	$	250,000
Licensing Fees:	$	50,000
Miscellaneous:	$	10,000
Total Other Annual Expenses	**$**	**310,000**
Total Fixed Costs	**$**	**279,704,283**

Investment Summary

Bare Module Cost/ APEA Inputs			
Fabricated Equipment	$	278,741,190	
Process Machinery	$	1,208,559,165	
Spares	$	6,896,827	
Storage	$	4,157,749	
Other Equipment	$	-	
Catalysts	$	26,413,952	
Computers, Software, Etc.	$	-	
Total Bare Module Costs:			**$ 1,524,768,882**
Direct Permanent Investment			
Cost of Site Preparations:	$	76,238,444	
Cost of Service Facilities:	$	76,238,444	
Allocated Costs for utility plants and related facilities:	$	-	
Direct Permanent Investment			**$ 1,677,245,771**
Total Depreciable Capital			
Cost of Contingencies & Contractor Fees	$	301,904,239	
Total Depreciable Capital			**$ 1,979,150,009**
Total Permanent Investment			
Cost of Land:	$	39,583,000	
Cost of Royalties:	$	-	
Cost of Plant Start-Up:	$	197,915,001	
Total Permanent Investment - Unadjusted			$ 2,216,648,010
Site Factor			1.00
Total Permanent Investment			**$ 2,216,648,010**

Working Capital

		2021		**2022**		**2023**
Accounts Receivable	$	1,917,370	$	958,685	$	958,685
Cash Reserves	$	11,818,554	$	5,909,277	$	5,909,277
Accounts Payable	$	(3,812,361)	$	(1,906,180)	$	(1,906,180)
Green Crude Inventory	$	255,649	$	127,825	$	127,825
Raw Materials	$	155,171	$	77,586	$	77,586
Total	**$**	**10,334,384**	**$**	**5,167,192**	**$**	**5,167,192**
Present Value at 15%	*$*	*7,814,279*	*$*	*3,397,513*	*$*	*2,954,359*

Total Capital Investment		**$ 2,230,814,161**

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2019	0%		-	-	-	-	-	-	-	-	-	-	-	-
2020	0%		-	(2,216,648,000)	-	-	-	-	-	-	-	-	(2,216,648,000)	(1,927,520,000)
2021	0%		-	-	(10,334,400)	-	-	-	-	-	-	-	(10,334,400)	(1,935,334,300)
2022	45%	$72.00	23,328,000	-	(5,167,200)	(37,991,400)	(279,704,300)	(395,830,000)	-	(690,197,600)	158,745,500	(531,452,200)	(140,789,400)	(2,027,905,600)
2023	68%	$73.44	35,691,800	-	(5,167,200)	(58,126,800)	(285,298,400)	(633,328,000)	-	(941,061,300)	216,444,100	(724,617,200)	(96,456,400)	(2,083,054,800)
2024	90%	$74.91	48,540,900	-	-	(79,052,400)	(291,004,300)	(379,996,800)	-	(701,512,600)	161,347,900	(540,164,700)	(160,167,900)	(2,162,686,600)
2025	90%	$76.41	49,511,700	-	-	(80,633,500)	(296,824,400)	(227,998,100)	-	(555,944,200)	127,867,200	(428,077,100)	(200,079,000)	(2,249,186,300)
2026	90%	$77.94	50,502,000	-	-	(82,246,100)	(302,760,900)	(227,998,100)	-	(562,503,200)	129,375,700	(433,127,400)	(205,129,300)	(2,326,302,000)
2027	90%	$79.49	51,512,000	-	-	(83,891,000)	(308,816,100)	(113,999,000)	-	(455,194,200)	104,694,700	(350,499,500)	(236,500,500)	(2,403,614,400)
2028	90%	$81.08	52,542,200	-	20,668,800	(85,568,900)	(314,992,500)	-	-	(348,019,100)	80,044,400	(267,974,700)	(247,305,900)	(2,473,914,200)

Profitability Measures

The Internal Rate of Return (IRR) for this project is Negative IRR

The Net Present Value (NPV) of this project in 2019 is ############

ROI Analysis (Third Production Year)

Annual Sales	**48,540,902**
Annual Costs	**(370,056,739)**
Depreciation	**(177,331,841)**
Income Tax	**114,734,966**
Net Earnings	**(384,112,711)**
Total Capital Investment	**2,237,316,779**
ROI	**-17.17%**

Sensitivity Analyses

Note: The Sensitivity Analyses section below takes quite a bit of memory to update each time a cell is changed; therefore, automatic calculations are turned off. After making your axis selections, press "F9" to recalculate the IRR values. (These two lines may be deleted before printing.)

	Vary Initial Value by +/-
x-axis	99%
y-axis	98%

		Total Permanent Investment										
		$22,166,480	$461,062,786	$899,959,092	$1,338,855,398	$1,777,751,704	***$2,216,648,010***	$2,655,544,316	$3,094,440,623	$3,533,336,929	$3,972,233,235	$4,411,129,541
Variable Costs	$1,435,229	541.67%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$18,033,228	326.08%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$34,631,227	45.61%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$51,229,226	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$67,827,225	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$84,425,224	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$101,023,223	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$117,621,223	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$134,219,222	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$150,817,221	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$167,415,220	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR

Process Title: ***AIR TO FUELS™***
Product: ***Green Crude***
Plant Site Location: ***Victoria County, Texas***

Timeline:

Number of Years for Design	1	(must be whole number)
Number of Years for Construction	2	(must be whole number)
Number of Years for Production	7	
Total Number of Years for Project	10	
Start Year	2019	
Site Factor	1.00	

Continuous Operation:

Days per Year	360	
OR		
Hours per Year	0	
OR		
Operating Factor	0.0000	(if multiple entries, "Operating Factor" is used)

Discrete Operation: (cannot use Continuous AND Discrete. If both entered, Discrete use

Hours per Day	0	
AND		
Days per Year	0	

Production Capacity	90%	of Design Capacity
Start production at	50%	of Production Capacity
Years to achieve full capacity	2	
Number of Shifts	5	
Depreciation Schedule	5 year	
Income Tax Rate	23%	
Cost of Capital (for the NPV Calculation)	15%	(discount rate)
General Inflation Rate	2%	
Product Inflation Rate	2%	
Variable Cost Inflation Rate	2%	
Fixed Cost Inflation Rate	2%	

Product Information:

Enter Product Units (i.e. lb, gram, gal, etc)	*bbl*	
Price Per Unit	$72.00	/bbl
Number of units per:	(Specify ONE of the three. If multiple entries, "Year" is used.)	
Year	-	bbl per Year
OR		
Day	2,000	bbl per Day

OR

Hour - bbl per Hour

Raw Materials

	Raw Material:	Unit:	Required Ratio:		Cost of Raw Material:	
1	Air (CO2)	ft^3	2.28E+07	ft^3 per bbl of Green Crude	$0.000E+00	per ft^3
2	Electrolysis Water	gal	273.28	gal per bbl of Green Crude	$8.000E-04	per gal
3	Carbon Capture Water	gal	552.74	gal per bbl of Green Crude	$8.000E-04	per gal
4	KOH	kg	84.39183673	kg per bbl of Green Crude	$0.800	per kg
5	Ca(OH)2	kg	58.27036424	kg per bbl of Green Crude	$0.330	per kg
6						
7						
8						
9						
10						
	Total Weighted Average:				$87.404	per bbl of Gre

Byproducts

	Byproduct:	Unit:	Ratio to Product		Byproduct Selling Price	
1	Lubricants (Heavy Alks)	kg	26.11057806	kg per bbl of Green Crude	$1.240	per kg
2	Oxygen	kg	920.63	kg per bbl of Green Crude	$2.000E-03	per kg
3						
4						
5						
6						
7						
8						
9						
10						
	Total Weighted Average:				$34.218	per bbl of Gre

Utilities

	Utility:	Unit:	Required Ratio		Utility Cost	
1	Cooling Water	gal	73.04	gal per bbl of Green Crude	$1.000E-04	per gal
2	Chilled Water	GJ	9.94685683	GJ per bbl of Green Crude	$5.000	per GJ
3	-30F Refrig (ammonia)	GJ	8.43E-02	GJ per bbl of Green Crude	$13.170	per GJ
4	-150F Refrig (ethylene)	GJ	0.080964996	GJ per bbl of Green Crude	$33.200	per GJ
5	150psi Steam	lb	88.81208191	lb per bbl of Green Crude	$7.000E-03	per lb
6	30psi Steam	lb	52.57525084	lb per bbl of Green Crude	$5.000E-03	per lb
7	Fuel Gas	SCF	266.2403086	SCF per bbl of Green Crude	$5.000E-03	per SCF
8	Electricity	kWh	0	kWh per bbl of Green Crude	$0.070	per kWh
9						
10						
	Total Weighted Average:				$55.756	per bbl of Gre

ed by default)

MACRS Depreciation Schedule:

	5 year	*7 year*	*10 year*	*15 year*	*20 year*
1	20.00%	14.29%	10.00%	5.00%	3.75%
2	32.00%	24.49%	18.00%	9.50%	7.22%
3	19.20%	17.49%	14.40%	8.55%	6.68%
4	11.52%	12.49%	11.52%	7.70%	6.18%
5	11.52%	8.93%	9.22%	6.93%	5.71%
6	5.76%	8.92%	7.37%	6.23%	5.29%
7		8.93%	6.55%	5.90%	4.89%
8		4.46%	6.55%	5.90%	4.52%
9			6.56%	5.91%	4.46%
10			6.55%	5.90%	4.46%
11			3.28%	5.91%	4.46%
12				5.90%	4.46%
13				5.91%	4.46%
14				5.90%	4.46%
15				5.91%	4.46%
16				2.95%	4.46%
17					4.46%
18					4.46%
19					4.46%
20					4.46%
21					2.23%

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Equipment Costs

Equipment Description	Type	Purchase Cost	Bare Module Factor	Bare Module Cost
Name	(must be filled-in!)		(default 3.21 if blank)	
BIDW Centrifugal Fans (113)	Process Machinery	$6,773,321	2.15	$14,562,640
Cooling Tower (absorption)	Process Machinery	$561,496		$1,802,402
McPhy Aug McLyzer 800-30 (135	Process Machinery	$378,546,610	1.00	$378,546,610
Solar Panels (115 acres, 50MW)	Process Machinery	$812,500,988	1.00	$812,500,988
Spare Fans (10)	Spares	$599,408.94	2.15	$1,288,729
Spare Electrolyzers (2)	Spares	$5,608,097.92	1.00	$5,608,098
FT Reactor	Fabricated Equipment	$3,520,651.81		$11,301,292
FT Catalyst	Catalysts	$14,007,553	1.50	$21,011,330
High T WGS Catalyst	Catalysts	$1,523	1.50	$2,284
KOH	Catalysts	$5,238,095.24	1.00	$5,238,095
Ca(OH)2	Catalysts	$162,242	1.00	$162,242
SCREWHX (Screw Extruder)	Fabricated Equipment	$2,297,556		$7,375,156
Flash and Distillation				$0
FLUFLASH	Fabricated Equipment	$903,532	2.50	$2,258,830
HTWGS Reactor	Fabricated Equipment	$321,027	1.50	$481,541
AIRSEP	Fabricated Equipment	$8,093,404	2.50	$20,233,510
FLASH1	Fabricated Equipment	$674,546	2.50	$1,686,366
FLASH3	Fabricated Equipment	$340,822	2.50	$852,055
FLASH4	Fabricated Equipment	$202,689	2.50	$506,722
FLASHLUB	Fabricated Equipment	$301,632.44	2.50	$754,081
DECANT1	Fabricated Equipment	$267,454.13	2.50	$668,635
Distillation Column 1	Fabricated Equipment	$219,525	4.16	$913,224
Reflux Accumulator 1	Fabricated Equipment	$230,472	3.05	$702,940
Reboiler 1	Fabricated Equipment	$108,174		$347,239
Distillation Pump	Fabricated Equipment	$14,469	3.30	$47,748
Condenser 1	Fabricated Equipment	$3,086,884		$9,908,898
Pumps & Compressors				$0
KOHPUMP	Fabricated Equipment	$7,516	3.30	$24,803
CAPUMP	Fabricated Equipment	$2,358	3.30	$7,781
COMP1	Fabricated Equipment	$18,192,902	2.15	$39,114,740
COMP2	Fabricated Equipment	$18,072,771	2.15	$38,856,458
COMP3	Fabricated Equipment	$3,125,525	2.15	$6,719,879
FLUECOMP	Fabricated Equipment	$4,834,256	2.15	$10,393,650
Cooling Tower (utility)	Process Machinery	$357,173		$1,146,525
				$0
				$0
SMR Plant (Option, Fbm=0)	Process Machinery	$67,303,151	0.00	$0
Additional Equipment				$129,743,391
Total				***1,524,768,882***

(Note: The first 38 equipment items are displayed in the Input Summary tab. Items listed below are included in calculating the total bare module cost.)

ADDITIONAL EQUIPMENT

Equipment Description		Purchase Cost	Bare Module Factor	Bare Module Cost
Name	**Type**		(default 3.21 if blank)	
Heat Exchangers				$0
H2OHYD1	Fabricated Equipment	$44,043	3	$139,616
H2OHYD2	Fabricated Equipment	$9,045	3	$28,673
CAHYDRHX	Fabricated Equipment	$31,714	3	$100,535
COMP1HX	Fabricated Equipment	$26,475	3	$83,926
COMP2HX	Fabricated Equipment	$19,104	3	$60,560
COMP3HX	Fabricated Equipment	$75,339	3	$238,824
ECONOM1	Fabricated Equipment	$36,873,699	3	$116,889,627
ECONOM2	Fabricated Equipment	$404,916	3	$1,283,582
WGSFLAHX	Fabricated Equipment	$144,876	3	$459,258
LIQ2HX1	Fabricated Equipment	$37,414	3	$118,602
LUBEHX	Fabricated Equipment	$43,860	3	$139,037
Fired Heaters				$0
KILNHT	Fabricated Equipment	$890,625	2	$1,950,469
FEEDHEAT	Fabricated Equipment	$1,207,799	2	$2,645,081
COOLER1	Fabricated Equipment	$261,015	2	$571,623
DECANTH	Fabricated Equipment	$141,732	2	$310,392
FUELHEAT	Fabricated Equipment	$103,507	2	$226,681
LIQFLAH	Fabricated Equipment	$154,076	2	$337,426
LUBEHEAT	Fabricated Equipment	$791	2	$1,732
Storage				$0
PELLETRX	Storage	$1,215,359	3	$3,706,845
HYDRATOR	Storage	$52,252	3	$159,369
Liquid Storage Sep	Storage	$38,828		$124,637
CaCO3 Storage	Storage	$51,993		$166,898
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0

APEA Inputs

(Note: If both APEA and Equipment Costs are entered, APEA entries are used for calculations)

Total Direct Materials and Labor Costs	$0
Miscellaneous Installation Costs	$0
Material and Labor G&A Overhead and Contractor Fees	$0
Contractor Engineering Costs	$0
Indirect Costs	$0
Total	$0

Bare Module Factor Calculator:

Use the tool below to calculate a particular bare module factor, then input in the required colu

(Note, if no bare module factor is entered, the default of 3.21 will be used)

Cost of Installation Materials:	**71%** of Equipment Purchase Cost
Cost of Installation Labor:	**54%** of Equipment Purchase Cost
Cost for Freight, Insurances, and Taxes:	**9%** of Equipment Purchase Cost
Cost of Construction Overhead:	**57%** of Equipment Purchase Cost
Cost of Contractor Engineering Expenses:	**30%** of Equipment Purchase Cost
Total Derived Bare Module Factor:	***3.21*** of Equipment Purchase Cost

mn to the left:

Fixed Costs

Operations

Operators per Shift:	13	(assuming 5
Direct Wages and Benefits:	$40	/operator hour
Direct Salaries and Benefits:	15%	of Direct Wages and B
Operating Supplies and Services:	6%	of Direct Wages and B
Technical Assistance to Manufacturing:	$12,000.00	per year, for each Ope
Control Laboratory:	$13,000.00	per year, for each Ope

Maintenance

Wages and Benefits:	4.50%	of Total Depreciable C
Salaries and Benefits:	25.00%	of Maintenance Wages
Materials and Services:	100.00%	of Maintenance Wages
Maintenance Overhead:	5.00%	of Maintenance Wages

Operating Overhead

General Plant Overhead:	7.10%	of Maintenance and O
Mechanical Department Services:	2.40%	of Maintenance and O
Employee Relations Department	5.90%	of Maintenance and O
Business Services	7.40%	of Maintenance and O

Property Taxes and Insurance

Property Taxes and Insurance:	2.00%	of Total Depreciable C

Straight Line Depreciation

Direct Plant:	8.00%	of Total Depreciable Capital, less		1.18
Allocated Plant:	6.00%	of	1.18	times the Allocated Co

Other Annual Expenses

Rental Fees (Office and Laboratory Space):	$250,000
Licensing Fees:	$50,000
Miscellaneous:	$10,000

Depletion Allowance

Annual Depletion Allowance:	$0

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apital

times the Allocated Costs
for Utility Plants and Related Facilities
sts for Utility Plants and Related Facilities

Total Permanent Investment

	% of Total Permanent Investment	
Year: **2020**	100%	(default is first year of Construction, otherw
2021	0%	
2022	0%	
2023	0%	

Cost of Site Preparations:	5.00%	of Total Bare Module Costs
Cost of Service Facilities:	5.00%	of Total Bare Module Costs
Allocated Costs for utility plants and related facilities:	$0	
Cost of Contingencies and Contractor Fees:	18.00%	of Direct Permanent Investm
Cost of Land:	2.00%	of Total Depreciable Capital
Cost of Royalties:	$0	
Cost of Plant Start-Up:	10.00%	of Total Depreciable Capital

ıise over-ride this year)

ıent

Other Variable Costs

General Expenses

Selling / Transfer Expenses:	3.00% of Sales
Direct Research:	4.80% of Sales
Allocated Research:	0.50% of Sales
Administrative Expense:	2.00% of Sales
Management Incentive Compensation:	1.25% of Sales

Working Capital

Accounts Receivable	a	**30 Days**
Cash Reserves (excluding Raw Materials)	a	**30 Days**
Accounts Payable	a	**30 Days**
Green Crude Inventory	a	**4 Days**
Raw Materials	a	**2 Days**

Appendix B

Shell-and-Tube Heat Exchanger Detailed Design Specifications

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: H2OHYD1	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 257 - 3750 mm	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 13.4 m²	Shells/unit 1		Surf/shell(eff.)	13.4 m²	
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		CAOH2H		HYDH2OC	
11	Fluid quantity, Total	kg/s	14.4022		3.9585	
12	Vapor (In/Out)	kg/s	0	0	0	0
13	Liquid	kg/s	14.4022	14.4022	3.9585	3.9585
14	Noncondensable	kg/s	0	0	0	0
15						
16	Temperature (In/Out)	°C	90	57.78	25	62.22
17	Bubble / Dew point	°C	/	/	/	/
18	Density Vapor/Liquid	kg/m³	/ 965.71	/ 985.26	/ 997.17	/ 981.99
19	Viscosity	mPa-s	/ 0.3149	/ 0.4944	/ 0.9125	/ 0.4583
20	Molecular wt, Vap					
21	Molecular wt, NC					
22	Specific heat	kJ/(kg-K)	/ 4.199	/ 4.176	/ 4.179	/ 4.185
23	Thermal conductivity	W/(m-K)	/ 0.6795	/ 0.6516	/ 0.607	/ 0.6557
24	Latent heat	kJ/kg				
25	Pressure (abs)	bar	1	0.91643	1	0.96741
26	Velocity (Mean/Max)	m/s	0.53 / 0.77		0.38 / 0.38	
27	Pressure drop, allow./calc.	bar	0.11	0.08357	0.2	0.03259
28	Fouling resistance (min)	m²-K/W	0		0	0 Ao based
29	Heat exchanged 615.8	kW		MTD (corrected)	30.29	°C
30	Transfer rate, Service 1516.3		Dirty 1527.9		Clean 1527.9	W/(m²-K)

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32			Shell Side		Tube Side	
33	Design/Vacuum/test pressure	bar	3 / /		3 / /	
34	Design temperature	°C	125		125	
35	Number passes per shell		1		1	
36	Corrosion allowance	mm	3.18		3.18	
37	Connections	In mm	1 152.4 / -		1 50.8 / -	
38	Size/Rating	Out	1 152.4 / -		1 50.8 / -	
39	ID	Intermediate	1 / -		1 / -	

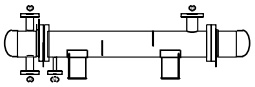
40	Tube #: 61	OD: 19.05	Tks. Average 2.11 mm	Length: 3750 mm	Pitch: 23.81 mm	Tube pattern:30
41	Tube type: Plain	Insert:None		Fin#: #/m	Material:Carbon Steel	
42	Shell Carbon Steel	ID 257.45	OD 273.05 mm	Shell cover -		
43	Channel or bonnet	Carbon Steel		Channel cover -		
44	Tubesheet-stationary	Carbon Steel	-	Tubesheet-floating -		
45	Floating head cover	-		Impingement protection None		
46	Baffle-cross Carbon Steel	Type	Single segmental	Cut(%d) 41.99	Horiz.Spacing: c/c 375	mm
47	Baffle-long -	Seal Type			Inlet 523.98	mm
48	Supports-tube	U-bend	0	Type		
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')		
50	Expansion joint	-	Type None			
51	RhoV2-Inlet nozzle 618	Bundle entrance 169		Bundle exit 165	kg/(m-s²)	
52	Gaskets - Shell side	-	Tube side	Flat Metal Jacket Fibe		
53	Floating head	-				
54	Code requirements	ASME Code Sec VIII Div 1		TEMA class R - refinery service		
55	Weight/Shell	581.9	Filled with water 757.2	Bundle 259.4	kg	
56	Remarks					
57						
58						

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: H2OHYD2	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 8.0709 - 53.1496 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 34.4 ft²	Shells/unit 1		Surf/shell(eff.) 34.4 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation	Shell Side		Tube Side		
10	Fluid name	HYDLPSI		HYDH2OW		
11	Fluid quantity, Total lb/h	1633		31417		
12	Vapor (In/Out) lb/h	1633	0	0	0	
13	Liquid lb/h	0	1633	31417	31417	
14	Noncondensable lb/h	0	0	0	0	
15						
16	Temperature (In/Out) °F	275	249.92	144	194	
17	Bubble / Dew point °F	250.38 / 250.38	249.92 / 249.92	/	/	
18	Density Vapor/Liquid lb/ft³	0.069 /	0.071 / 58.806	/ 61.305	/ 60.251	
19	Viscosity cp	0.0137 /	0.0132 / 0.2264	/ 0.458	/ 0.3135	
20	Molecular wt, Vap	18.02	18.02			
21	Molecular wt, NC					
22	Specific heat BTU/(lb-F)	0.4615 /	0.4605 / 1.0152	/ 0.9996	/ 1.0042	
23	Thermal conductivity BTU/(ft-h-F)	0.016 /	0.015 / 0.4	/ 0.379	/ 0.392	
24	Latent heat BTU/lb	951.8	952.1			
25	Pressure (abs) psi	30	29.76	14.5	13.56	
26	Velocity (Mean/Max) ft/s	14.11 / 56.43		3.68 / 3.71		
27	Pressure drop, allow./calc. psi	2.9	0.24	2.9	0.94	
28	Fouling resistance (min) ft²-h-F/BTU	0		0	0 Ao based	
29	Heat exchanged 1573456 BTU/h			MTD (corrected) 78.92 °F		
30	Transfer rate, Service 578.9		Dirty 591.68		Clean 591.68 BTU/(h-ft²-F)	

31	**CONSTRUCTION OF ONE SHELL**				**Sketch**	
32		Shell Side	Tube Side			
33	Design/Vacuum/test pressure psi	43.51 / /	43.51 / /			
34	Design temperature °F	338	338			
35	Number passes per shell	1	2			
36	Corrosion allowance in	0.125	0.125			
37	Connections In in	1 3 / -	1 2 / -			
38	Size/Rating Out	1 0.75 / -	1 2 / -			
39	ID Intermediate	/ -	/ -			



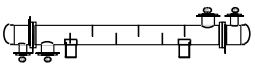
40	Tube #: 42	OD: 0.75	Tks. Average 0.083 in	Length: 53.1496 in	Pitch: 0.9375 in	Tube pattern: 30
41	Tube type: Plain	Insert: None	Fin#:	#/in	Material: Carbon Steel	
42	Shell Carbon Steel	ID 8.071	OD 8.625 in	Shell cover -		
43	Channel or bonnet Carbon Steel			Channel cover -		
44	Tubesheet-stationary Carbon Steel	-		Tubesheet-floating -		
45	Floating head cover -			Impingement protection None		
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 41.48	Horiz. Spacing: c/c 16.1417 in		
47	Baffle-long -	Seal Type		Inlet 16.9872 in		
48	Supports-tube U-bend	0	Type			
49	Bypass seal	Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')			
50	Expansion joint -	Type None				
51	RhoV2-Inlet nozzle 1126	Bundle entrance 68	Bundle exit 0 lb/(ft-s²)			
52	Gaskets - Shell side -	Tube side	Flat Metal Jacket Fibe			
53	Floating head -					
54	Code requirements ASME Code Sec VIII Div 1		TEMA class R - refinery service			
55	Weight/Shell 519.6	Filled with water 613.2	Bundle 184.3 lb			
56	Remarks					
57						
58						

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: CAHYDRHX	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 10.1181 - 100.393` in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 97.2 ft²	Shells/unit 1		Surf/shell(eff.) 97.2 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation	Shell Side		Tube Side		
10	Fluid name	CAOH2WHP		CAHYDCWI		
11	Fluid quantity, Total lb/h	117464		114510		
12	Vapor (In/Out) lb/h	0	0	0	0	
13	Liquid lb/h	117464	117464	114510	114510	
14	Noncondensable lb/h	0	0	0	0	
15						
16	Temperature (In/Out) °F	131.29	77.01	41	59	
17	Bubble / Dew point °F	/	/	/	/	
18	Density Vapor/Liquid lb/ft³	/ 61.594	/ 62.339	/ 62.43	/ 62.379	
19	Viscosity cp	/ 0.5161	/ 0.92	/ 1.4836	/ 1.1498	
20	Molecular wt, Vap					
21	Molecular wt, NC					
22	Specific heat BTU/(lb-F)	/ 0.997	/ 0.9956	/ 1.0034	/ 0.9996	
23	Thermal conductivity BTU/(ft-h-F)	/ 0.375	/ 0.351	/ 0.331	/ 0.341	
24	Latent heat BTU/lb					
25	Pressure (abs) psi	29.01	27.84	14.5	13.14	
26	Velocity (Mean/Max) ft/s	2.02 / 2.47		4.49 / 4.49		
27	Pressure drop, allow./calc. psi	2.9	1.17	2.9	1.36	
28	Fouling resistance (min) ft²-h-F/BTU	0		0	0 Ao based	
29	Heat exchanged 2063693 BTU/h			MTD (corrected) 52.23 °F		
30	Transfer rate, Service 406.61	Dirty 409.28		Clean 409.28 BTU/(h-ft²-F)		

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32			Shell Side	Tube Side		
33	Design/Vacuum/test pressure psi		43.51 / /	43.51 / /		
34	Design temperature °F		203	203		
35	Number passes per shell		1	1		
36	Corrosion allowance in		0.125	0.125		
37	Connections	In in	1 6 / -	1 3.5 / -		
38	Size/Rating	Out	1 6 / -	1 3.5 / -		
39	ID	Intermediate	1 / -	1 / -		



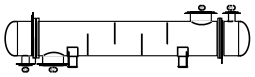
40	Tube #: 61	OD: 0.75	Tks. Average 0.083 in	Length: 00.3937 in	Pitch: 0.9375 in	Tube pattern: 30
41	Tube type: Plain	Insert: None		Fin#: #/in	Material: Carbon Steel	
42	Shell Carbon Steel	ID 10.136	OD 10.75 in	Shell cover -		
43	Channel or bonnet Carbon Steel			Channel cover -		
44	Tubesheet-stationary Carbon Steel	-		Tubesheet-floating -		
45	Floating head cover -			Impingement protection None		
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 41.99	Horiz. Spacing: c/c 12.2047 in		
47	Baffle-long -	Seal Type		Inlet 18.1683 in		
48	Supports-tube U-bend	0		Type		
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')		
50	Expansion joint -		Type None			
51	RhoV2-Inlet nozzle 429	Bundle entrance 151		Bundle exit 149 lb/(ft-s²)		
52	Gaskets - Shell side -		Tube side	Flat Metal Jacket Fibe		
53	Floating head -					
54	Code requirements	ASME Code Sec VIII Div 1		TEMA class R - refinery service		
55	Weight/Shell 1020.6	Filled with water 1306.1		Bundle 420 lb		
56	Remarks					
57						
58						

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: COMP1HX	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 21.2598 - 112.2047 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 588.6 ft²	Shells/unit 1		Surf/shell(eff.) 588.6 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation	Shell Side		Tube Side		
10	Fluid name	CO26HOT		C1HXCWI		
11	Fluid quantity, Total lb/h	69777		108300		
12	Vapor (In/Out) lb/h	69777	69777	0	0	
13	Liquid lb/h	0	0	108300	108300	
14	Noncondensable lb/h	0	0	0	0	
15						
16	Temperature (In/Out) °F	330.69	120.87	90	120	
17	Bubble / Dew point °F	/	/	/	/	
18	Density Vapor/Liquid lb/ft³	0.452 /	0.591 /	/ 61.614	/ 60.593	
19	Viscosity cp	0.0213 /	0.0161 /	/ 0.7827	/ 0.5705	
20	Molecular wt, Vap	44.01	44.01			
21	Molecular wt, NC					
22	Specific heat BTU/(lb-F)	0.2331 /	0.2087 /	/ 0.9905	/ 1.0084	
23	Thermal conductivity BTU/(ft-h-F)	0.016 /	0.011 /	/ 0.356	/ 0.368	
24	Latent heat BTU/lb					
25	Pressure (abs) psi	87.02	83.68	14.5	14.09	
26	Velocity (Mean/Max) ft/s	45.73 / 55.5		0.8 / 0.81		
27	Pressure drop, allow./calc. psi	3.77	3.34	2.9	0.42	
28	Fouling resistance (min) ft²-h-F/BTU	0		0	0 Ao based	
29	Heat exchanged 3246910 BTU/h			MTD (corrected) 95.69 °F		
30	Transfer rate, Service 57.65	Dirty 57.84		Clean 57.84 BTU/(h-ft²-F)		

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32		Shell Side		Tube Side		
33	Design/Vacuum/test pressure psi	101.53 / /		43.51 / /		
34	Design temperature °F	401		401		
35	Number passes per shell	1		1		
36	Corrosion allowance in	0.125		0.125		
37	Connections In in	1 12 / -		1 4.026 / -		
38	Size/Rating Out	1 12 / -		1 3.548 / -		
39	ID Intermediate	/ -		/ -		



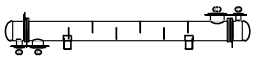
40	Tube #: 330	OD: 0.75	Tks. Average 0.083 in	Length: 12.2047 in	Pitch: 0.9375 in	Tube pattern: 30
41	Tube type: Plain	Insert: None		Fin#: #/in	Material: Carbon Steel	
42	Shell Carbon Steel	ID 21.25	OD 22 in	Shell cover -		
43	Channel or bonnet Carbon Steel			Channel cover -		
44	Tubesheet-stationary Carbon Steel	-		Tubesheet-floating -		
45	Floating head cover -			Impingement protection None		
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 38.54	Horiz. Spacing: c/c 16.3386 in		
47	Baffle-long -	Seal Type		Inlet 29.999 in		
48	Supports-tube U-bend	0		Type		
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')		
50	Expansion joint -		Type None			
51	RhoV2-Inlet nozzle 1349	Bundle entrance 1084		Bundle exit 755 lb/(ft-s²)		
52	Gaskets - Shell side -		Tube side	Flat Metal Jacket Fibe		
53	Floating head -					
54	Code requirements ASME Code Sec VIII Div 1			TEMA class R - refinery service		
55	Weight/Shell 3699	Filled with water 5073		Bundle 2191.3 lb		
56	Remarks					
57						
58						

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: COMP2HX	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 5.2362 - 159.4488 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 391.6 ft²	Shells/unit 1		Surf/shell(eff.) 391.6 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		CO218HOT		C2HXCWI	
11	Fluid quantity, Total	lb/h	69777		103928	
12	Vapor (In/Out)	lb/h	69777	69777	0	0
13	Liquid	lb/h	0	0	103928	103928
14	Noncondensable	lb/h	0	0	0	0
15						
16	Temperature (In/Out)	°F	323.25	121.58	90	120
17	Bubble / Dew point	°F	/	/	/	/
18	Density Vapor/Liquid	lb/ft³	1.315 /	1.744 /	/ 61.614	/ 60.593
19	Viscosity	cp	0.0211 /	0.0161 /	/ 0.7827	/ 0.5705
20	Molecular wt, Vap		44.01	44.01		
21	Molecular wt, NC					
22	Specific heat	BTU/(lb-F)	0.2324 /	0.2088 /	/ 0.9905	/ 1.0083
23	Thermal conductivity	BTU/(ft-h-F)	0.016 /	0.011 /	/ 0.356	/ 0.368
24	Latent heat	BTU/lb				
25	Pressure (abs)	psi	251.05	247.23	14.5	13.98
26	Velocity (Mean/Max)	ft/s	22.63 / 37.77		1.66 / 1.67	
27	Pressure drop, allow./calc.	psi	3.82	3.82	2.9	0.52
28	Fouling resistance (min)	ft²-h-F/BTU	0		0	0 Ao based
29	Heat exchanged 3115768	BTU/h		MTD (corrected) 94.11		°F
30	Transfer rate, Service 84.55		Dirty 84.74	Clean 84.74		BTU/(h-ft²-F)

31	**CONSTRUCTION OF ONE SHELL**						**Sketch**
32			Shell Side		Tube Side		
33	Design/Vacuum/test pressure	psi	290.08 / /		43.51 / /		
34	Design temperature	°F	392		392		
35	Number passes per shell		1		1		
36	Corrosion allowance	in	0.125		0.125		
37	Connections In	in	1 10.02 / -		1 4.026 / -		
38	Size/Rating Out		1 7.981 / -		1 3.548 / -		
39	ID Intermediate		/ -		/ -		



40	Tube #: 153	OD: 0.75	Tks. Average 0.083	in	Length: 59.4488	in	Pitch: 0.9375	in	Tube pattern: 30
41	Tube type: Plain		Insert: None		Fin#:	#/in	Material: Carbon Steel		
42	Shell Carbon Steel	ID 15.25	OD 16	in	Shell cover -				
43	Channel or bonnet Carbon Steel				Channel cover -				
44	Tubesheet-stationary Carbon Steel	-			Tubesheet-floating -				
45	Floating head cover -				Impingement protection None				
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 39.35		Horiz. Spacing: c/c 18.8976	in			
47	Baffle-long -	Seal Type			Inlet 30.9636	in			
48	Supports-tube U-bend	0			Type				
49	Bypass seal		Tube-tubesheet joint		Expanded only (2 grooves)(App.A 'i')				
50	Expansion joint -		Type None						
51	RhoV2-Inlet nozzle 953		Bundle entrance 622		Bundle exit 322				lb/(ft-s²)
52	Gaskets - Shell side -		Tube side		Flat Metal Jacket Fibe				
53	Floating head -								
54	Code requirements	ASME Code Sec VIII Div 1			TEMA class	R - refinery service			
55	Weight/Shell	2847.4	Filled with water 3824.8		Bundle 1457		lb		
56	Remarks								
57									
58									

TEMA Sheet

Heat Exchanger Specification Sheet

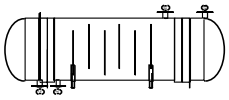
1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: COMP3HX	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 3.2677 - 47.2441 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 85.9 ft²	Shells/unit 1		Surf/shell(eff.) 85.9 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		CO225HOT		HPFDMX-3	
11	Fluid quantity, Total lb/h		69777		85758	
12	Vapor (In/Out) lb/h		69777	69777	85758	85758
13	Liquid lb/h		0	0	0	0
14	Noncondensable lb/h		0	0	0	0
15						
16	Temperature (In/Out) °F		178.63	140.38	90.32	98.61
17	Bubble / Dew point °F		/	/	/	/
18	Density Vapor/Liquid lb/ft³		2.33 /	2.463 /	0.554 /	0.537 /
19	Viscosity cp		0.0176 /	0.0166 /	0.0133 /	0.0134 /
20	Molecular wt, Vap		44.01	44.01	9.01	9.01
21	Molecular wt, NC					
22	Specific heat BTU/(lb-F)		0.2165 /	0.2114 /	0.8025 /	0.8041 /
23	Thermal conductivity BTU/(ft-h-F)		0.012 /	0.011 /	0.075 /	0.076 /
24	Latent heat BTU/lb					
25	Pressure (abs) psi		362.59	360.37	362.59	356.64
26	Velocity (Mean/Max) ft/s		26.71 / 29.24		197.38 / 200.54	
27	Pressure drop, allow./calc. psi		5.08	2.23	7.25	5.96
28	Fouling resistance (min) ft²-h-F/BTU		0		0	0 Ao based
29	Heat exchanged 571224 BTU/h			MTD (corrected) 63.95 °F		
30	Transfer rate, Service 103.94		Dirty 113.51	Clean 113.51 BTU/(h-ft²-F)		
31	**CONSTRUCTION OF ONE SHELL**				**Sketch**	
32			Shell Side	Tube Side		
33	Design/Vacuum/test pressure psi		406.11 / /	406.11 / /		
34	Design temperature °F		248	248		
35	Number passes per shell		1	1		
36	Corrosion allowance in		0.125	0.125		
37	Connections In in		1 8 / -	1 10 / -		
38	Size/Rating Out		1 8 / -	1 10 / -		
39	ID Intermediate		/ -	/ -		
40	Tube #: 119 OD: 0.75 Tks. Average 0.083 in		Length: 47.2441 in	Pitch: 0.9375 in	Tube pattern: 30	
41	Tube type: Plain	Insert: None	Fin#:	#/in	Material: Carbon Steel	
42	Shell Carbon Steel ID 13.25 OD 14 in			Shell cover -		
43	Channel or bonnet Carbon Steel			Channel cover -		
44	Tubesheet-stationary Carbon Steel -			Tubesheet-floating -		
45	Floating head cover -			Impingement protection None		
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 37.74	Horiz. Spacing: c/c 10.2362 in		
47	Baffle-long -	Seal Type		Inlet 16.9478 in		
48	Supports-tube U-bend	0	Type			
49	Bypass seal	Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')			
50	Expansion joint -	Type None				
51	RhoV2-Inlet nozzle 1336	Bundle entrance 1219	Bundle exit 1646 lb/(ft-s²)			
52	Gaskets - Shell side -	Tube side	Flat Metal Jacket Fibe			
53	Floating head -					
54	Code requirements ASME Code Sec VIII Div 1		TEMA class R - refinery service			
55	Weight/Shell 1532.2 Filled with water 1993.1		Bundle 429.9 lb			
56	Remarks					
57						
58						

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: ECONOM1	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 2375 - 5700 mm	Type: BEM	Horizontal	Connected in: 6 parallel	1 series	
7	Surf/unit(eff.) 15840.7 m²	Shells/unit 6		Surf/shell(eff.) 2640.1 m²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		FLUEHOT1		FEEDCOLD	
11	Fluid quantity, Total	kg/s	9.7891		19.5782	
12	Vapor (In/Out)	kg/s	9.7891	8.7018	19.5094	19.5782
13	Liquid	kg/s	0	1.0874	0.0688	0
14	Noncondensable	kg/s	0	0	0	0
15						
16	Temperature (In/Out)	°C	500	80.38	63.41	305
17	Bubble / Dew point	°C	-237.8 / 116.19	-237.8 / 116.16	-237.98 / 66.95	-237.99 / 66.93
18	Density Vapor/Liquid	kg/m³	3.33 /	6.83 / 937.29	7.64 / 960.59	4.45 /
19	Viscosity	mPa-s	0.0281 /	0.0153 / 0.3388	0.0145 / 0.416	0.0218 /
20	Molecular wt, Vap		8.57	8.03	8.55	8.57
21	Molecular wt, NC					
22	Specific heat	kJ/(kg-K)	3.687 /	3.709 / 4.333	3.534 / 4.131	3.672 /
23	Thermal conductivity	W/(m-K)	0.2583 /	0.1459 / 0.3649	0.1411 / 0.2791	0.2204 /
24	Latent heat	kJ/kg	2197.3	2195.8	1304.5	2231.1
25	Pressure (abs)	bar	25	24.97371	25	24.97829
26	Velocity (Mean/Max)	m/s	0.74 / 1.36		0.38 / 0.49	
27	Pressure drop, allow./calc.	bar	0.35	0.02629	0.5	0.02171
28	Fouling resistance (min)	m²-K/W	0		0	0 Ao based
29	Heat exchanged 17243.2	kW		MTD (corrected) 24.65	°C	
30	Transfer rate, Service 44.2		Dirty 45.8	Clean 45.8	W/(m²-K)	

31	**CONSTRUCTION OF ONE SHELL**						**Sketch**
32			Shell Side		Tube Side		
33	Design/Vacuum/test pressure	bar	28 / /		28 / /		
34	Design temperature	°C	535		535		
35	Number passes per shell		1		1		
36	Corrosion allowance	mm	3.18		3.18		
37	Connections	In mm	1 203.2 / -		1 203.2 / -		
38	Size/Rating	Out	1 152.4 / -		1 203.2 / -		
39	ID	Intermediate	1 / -		1 / -		



40	Tube #: 8709	OD: 19.05	Tks. Average 2.11	mm	Length: 5700	mm	Pitch: 23.81	mm Tube pattern:30
41	Tube type: Plain		Insert:None		Fin#:	#/m	Material:Carbon Steel	
42	Shell Carbon Steel	ID 2375	OD 2863	mm	Shell cover	-		
43	Channel or bonnet	Carbon Steel			Channel cover	-		
44	Tubesheet-stationary	Carbon Steel	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-cross Carbon Steel	Type	Single segmental	Cut(%d) 24.82	Horiz.	Spacing: c/c 685	mm	
47	Baffle-long -	Seal Type			Inlet	820.18	mm	
48	Supports-tube	U-bend	0		Type			
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')				
50	Expansion joint	-	Type None					
51	RhoV2-Inlet nozzle 1295	Bundle entrance 38		Bundle exit 54	kg/(m-s²)			
52	Gaskets - Shell side	-	Tube side	Flat Metal Jacket Fibe				
53	Floating head	-						
54	Code requirements	ASME Code Sec VIII Div 1		TEMA class	R - refinery service			
55	Weight/Shell	218697.8	Filled with water 239120.9	Bundle	74861.8	kg		
56	Remarks							
57								
58								

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: ECONOM2	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 650 - 4500 mm	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 126.9 m²	Shells/unit 1		Surf/shell(eff.) 126.9 m²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		FLUEHOT2		FEEDWARM	
11	Fluid quantity, Total	kg/s	9.7891		19.5782	
12	Vapor (In/Out)	kg/s	9.7891	9.7891	19.5782	19.5782
13	Liquid	kg/s	0	0	0	0
14	Noncondensable	kg/s	0	0	0	0
15						
16	Temperature (In/Out)	°C	500	332.77	305	387.74
17	Bubble / Dew point	°C	/	/	/	/
18	Density Vapor/Liquid	kg/m³	3.33 /	4.19 /	4.45 /	3.83 /
19	Viscosity	mPa-s	0.0281 /	0.0235 /	0.0218 /	0.024 /
20	Molecular wt, Vap		8.57	8.57	8.57	8.57
21	Molecular wt, NC					
22	Specific heat	kJ/(kg-K)	3.687 /	3.615 /	3.672 /	3.705 /
23	Thermal conductivity	W/(m-K)	0.2583 /	0.2117 /	0.2204 /	0.2454 /
24	Latent heat	kJ/kg				
25	Pressure (abs)	bar	25	24.6574	25	24.55072
26	Velocity (Mean/Max)	m/s	20.63 / 29.31		55.05 / 59.56	
27	Pressure drop, allow./calc.	bar	0.35	0.34261	0.5	0.44928
28	Fouling resistance (min)	m²-K/W	0		0	0 Ao based
29	Heat exchanged 5974.6	kW		MTD (corrected) 60.72		°C
30	Transfer rate, Service 775.7		Dirty 1049.8		Clean 1049.8	W/(m²-K)

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32			Shell Side		Tube Side	
33	Design/Vacuum/test pressure	bar	28 / /		28 / /	
34	Design temperature	°C	535		535	
35	Number passes per shell		1		1	
36	Corrosion allowance	mm	3.18		3.18	
37	Connections	In mm	1 457.2 / -		1 508 / -	
38	Size/Rating	Out	1 406.4 / -		1 508 / -	
39	ID	Intermediate	1 / -		1 / -	

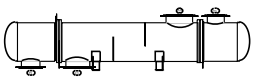
40	Tube #: 497	OD: 19.05	Tks. Average 2.11	mm	Length: 4500	mm	Pitch: 23.81	mm	Tube pattern:30
41	Tube type: Plain		Insert:None		Fin#:	#/m	Material:Carbon Steel		
42	Shell Carbon Steel	ID 650	OD 788	mm	Shell cover -				
43	Channel or bonnet	Carbon Steel			Channel cover -				
44	Tubesheet-stationary	Carbon Steel	-		Tubesheet-floating -				
45	Floating head cover	-			Impingement protection None				
46	Baffle-cross Carbon Steel	Type	Single segmental	Cut(%d) 40.48	Horiz.Spacing: c/c 685	mm			
47	Baffle-long -	Seal Type			Inlet 1104.97	mm			
48	Supports-tube	U-bend	0		Type				
49	Bypass seal		Tube-tubesheet joint		Expanded only (2 grooves)(App.A 'i')				
50	Expansion joint	-	Type None						
51	RhoV2-Inlet nozzle 2288	Bundle entrance 1481		Bundle exit 1144	kg/(m-s²)				
52	Gaskets - Shell side	-	Tube side	Flat Metal Jacket Fibe					
53	Floating head	-							
54	Code requirements	ASME Code Sec VIII Div 1		TEMA class R - refinery service					
55	Weight/Shell	13147	Filled with water 14939.2	Bundle 3085.7	kg				
56	Remarks								
57									
58									

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: WGSFLAHX	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 29.5276 - 106.2992 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 1025.5 ft²	Shells/unit 1		Surf/shell(eff.) 1025.5 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation		Shell Side		Tube Side	
10	Fluid name		FLU2HX		FLUECWI	
11	Fluid quantity, Total	lb/h	155402		1589900	
12	Vapor (In/Out)	lb/h	155402	134208	0	0
13	Liquid	lb/h	0	21194	1589900	1589900
14	Noncondensable	lb/h	0	0	0	0
15						
16	Temperature (In/Out)	°F	341.99	137.16	90	120
17	Bubble / Dew point	°F	-376.24 / 241.17	-376.35 / 240.46	/	/
18	Density Vapor/Liquid	lb/ft³	0.361 /	0.442 / 60.016	/ 61.614	/ 60.593
19	Viscosity	cp	0.0187 /	0.0145 / 0.46	/ 0.7827	/ 0.5705
20	Molecular wt, Vap		8.57	7.9		
21	Molecular wt, NC					
22	Specific heat	BTU/(lb-F)	0.8494 /	0.8951 / 0.9955	/ 0.9905	/ 1.0084
23	Thermal conductivity	BTU/(ft-h-F)	0.095 /	0.082 / 0.187	/ 0.356	/ 0.368
24	Latent heat	BTU/lb	940.2	887.4		
25	Pressure (abs)	psi	362.59	357.98	14.5	12.5
26	Velocity (Mean/Max)	ft/s	74.01 / 98.96		6.34 / 6.39	
27	Pressure drop, allow./calc.	psi	4.61	4.61	2.9	2.01
28	Fouling resistance (min)	ft²-h-F/BTU	0		0	0 Ao based
29	Heat exchanged 47667480	BTU/h		MTD (corrected) 104.21		°F
30	Transfer rate, Service 446.06		Dirty 447.29	Clean 447.29		BTU/(h-ft²-F)

31	**CONSTRUCTION OF ONE SHELL**						**Sketch**
32			Shell Side		Tube Side		
33	Design/Vacuum/test pressure	psi	406.11 / /		43.51 / /		
34	Design temperature	°F	410		410		
35	Number passes per shell		1		1		
36	Corrosion allowance	in	0.125		0.125		
37	Connections In	in	1 19.25 / -		1 13.25 / -		
38	Size/Rating Out		1 17.25 / -		1 12 / -		
39	ID Intermediate		/ -		/ -		



40	Tube #: 613	OD: 0.75	Tks. Average 0.083	in	Length: 06.2992	in	Pitch: 0.9375	in Tube pattern: 30
41	Tube type: Plain		Insert: None		Fin#:	#/in	Material: Carbon Steel	
42	Shell Carbon Steel	ID 29.5276	OD 30.5512	in	Shell cover -			
43	Channel or bonnet Carbon Steel				Channel cover -			
44	Tubesheet-stationary Carbon Steel	-			Tubesheet-floating -			
45	Floating head cover -				Impingement protection None			
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 39		Horiz. Spacing: c/c 23.0315	in		
47	Baffle-long -	Seal Type			Inlet 39.6053	in		
48	Supports-tube U-bend	0			Type			
49	Bypass seal		Tube-tubesheet joint		Expanded only (2 grooves)(App.A 'i')			
50	Expansion joint -		Type None					
51	RhoV2-Inlet nozzle 1263	Bundle entrance 1922			Bundle exit 1343			lb/(ft-s²)
52	Gaskets - Shell side -		Tube side		Flat Metal Jacket Fibe			
53	Floating head -							
54	Code requirements	ASME Code Sec VIII Div 1			TEMA class R - refinery service			
55	Weight/Shell 7935.6	Filled with water 11335.3			Bundle 4084.7		lb	
56	Remarks							
57								
58								

TEMA Sheet

Heat Exchanger Specification Sheet

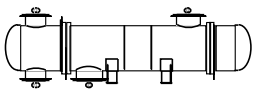
1	Company:							
2	Location:							
3	Service of Unit:		Our Reference:					
4	Item No.:		Your Reference:					
5	Date:	Rev No.:	Job No.:					
6	Size: 7.2441 - 236.220	in	Type: BEM	Horizontal		Connected in: 2 parallel	2 series	
7	Surf/unit(eff.)	3330 ft²	Shells/unit 4			Surf/shell(eff.)	832.5 ft²	
8	**PERFORMANCE OF ONE UNIT**							
9	Fluid allocation		Shell Side			Tube Side		
10	Fluid name		FTPRODH			SYNGASC		
11	Fluid quantity, Total	lb/h	69625			69625		
12	Vapor (In/Out)	lb/h	69625	60860		69625	69625	
13	Liquid	lb/h	0	8765		0	0	
14	Noncondensable	lb/h	0	0		0	0	
15								
16	Temperature (In/Out)	°F	572	292.92		193.15	517.96	
17	Bubble / Dew point	°F	-395.23 / 537.27	-395.32 / 536.18		/	/	
18	Density Vapor/Liquid	lb/ft³	0.351 /	0.426 / 42.607		0.418 /	0.276 /	
19	Viscosity	cp	0.0218 /	0.0167 / 0.2035		0.0157 /	0.0211 /	
20	Molecular wt, Vap		10.72	9.73		8.07	8.07	
21	Molecular wt, NC							
22	Specific heat	BTU/(lb-F)	0.8424 /	0.8443 / 0.8681		0.8842 /	0.9033 /	
23	Thermal conductivity	BTU/(ft-h-F)	0.102 /	0.081 / 0.095		0.086 /	0.119 /	
24	Latent heat	BTU/lb	107.6	927.9				
25	Pressure (abs)	psi	362.59	355.96		362.59	358.47	
26	Velocity (Mean/Max)	ft/s	30.62 / 56.75			68.46 / 86.08		
27	Pressure drop, allow./calc.	psi	7.06	6.64		7.25	4.12	
28	Fouling resistance (min)	ft²-h-F/BTU	0			0	0 Ao based	
29	Heat exchanged 20243440	BTU/h			MTD (corrected)	54.6	°F	
30	Transfer rate, Service 111.33		Dirty 113.67		Clean	113.67	BTU/(h-ft²-F)	
31	**CONSTRUCTION OF ONE SHELL**						**Sketch**	
32			Shell Side		Tube Side			
33	Design/Vacuum/test pressure	psi	406.11 / /		406.11 / /			
34	Design temperature	°F	635		635			
35	Number passes per shell		1		1			
36	Corrosion allowance	in	0.125		0.125			
37	Connections	In in	1 10 / -		1 8 / -			
38	Size/Rating	Out	1 10 / -		1 8 / -			
39	ID	Intermediate	1 10 / -		1 8 / -			
40	Tube #: 219	OD: 0.75	Tks. Average 0.083	in	Length: 36.2205	in	Pitch: 0.9375 in	Tube pattern: 30
41	Tube type: Plain		Insert: None		Fin#:	#/in	Material: Carbon Steel	
42	Shell Carbon Steel	ID 17.25	OD 18	in	Shell cover	-		
43	Channel or bonnet	Carbon Steel			Channel cover	-		
44	Tubesheet-stationary	Carbon Steel	-		Tubesheet-floating	-		
45	Floating head cover	-			Impingement protection	None		
46	Baffle-cross Carbon Steel	Type	Single segmental	Cut(%d) 40.59	Horiz.	Spacing: c/c 23.2284	in	
47	Baffle-long -	Seal Type			Inlet	34.8612	in	
48	Supports-tube	U-bend	0		Type			
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')				
50	Expansion joint	-	Type None					
51	RhoV2-Inlet nozzle 888	Bundle entrance 384	Bundle exit 430	lb/(ft-s²)				
52	Gaskets - Shell side	-	Tube side	Flat Metal Jacket Fibe				
53	Floating head	-						
54	Code requirements	ASME Code Sec VIII Div 1	TEMA class	R - refinery service				
55	Weight/Shell	5614.7 Filled with water 7634.6	Bundle	2964.5 lb				
56	Remarks							
57								
58								

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: FTPRODHX	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 24.6063 - 76.7717 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 532.5 ft²	Shells/unit 1		Surf/shell(eff.) 532.5 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation	Shell Side		Tube Side		
10	Fluid name	FTPRODW		FTCWIN		
11	Fluid quantity, Total lb/h	69625		796083		
12	Vapor (In/Out) lb/h	60742	43139	0	0	
13	Liquid lb/h	8883	26486	796083	796083	
14	Noncondensable lb/h	0	0	0	0	
15						
16	Temperature (In/Out) °F	292.5	172.79	90	120	
17	Bubble / Dew point °F	-395.32 / 536.1	-395.34 / 535.84	/	/	
18	Density Vapor/Liquid lb/ft³	0.428 / 42.444	0.425 / 51.856	/ 61.614	/ 60.593	
19	Viscosity cp	0.0167 / 0.1979	0.0134 / 0.3531	/ 0.7827	/ 0.5705	
20	Molecular wt, Vap	9.72	8.15			
21	Molecular wt, NC					
22	Specific heat BTU/(lb-F)	0.8413 / 0.8828	0.971 / 0.9452	/ 0.9905	/ 1.0084	
23	Thermal conductivity BTU/(ft-h-F)	0.08 / 0.095	0.086 / 0.145	/ 0.356	/ 0.368	
24	Latent heat BTU/lb	900	789.5			
25	Pressure (abs) psi	355.54	353.94	14.5	10.24	
26	Velocity (Mean/Max) ft/s	22.44 / 52.25		8.65 / 8.92		
27	Pressure drop, allow./calc. psi	4.87	1.6	2.9	4.27	
28	Fouling resistance (min) ft²-h-F/BTU	0		0	0 Ao based	
29	Heat exchanged 23867430 BTU/h			MTD (corrected) 129.49 °F		
30	Transfer rate, Service 346.13		Dirty 406.52		Clean 406.52 BTU/(h-ft²-F)	

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**	
32			Shell Side		Tube Side		
33	Design/Vacuum/test pressure psi		391.6 / /		43.51 / /		
34	Design temperature °F		356		356		
35	Number passes per shell		1		2		
36	Corrosion allowance in		0.125		0.125		
37	Connections	In in	1 12 / -		1 10.02 / -		
38	Size/Rating	Out	1 13.25 / -		1 10.02 / -		
39	ID	Intermediate	/ -		/ -		



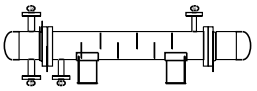
40	Tube #: 450	OD: 0.75	Tks. Average 0.083 in	Length: 76.7717 in	Pitch: 0.9375 in	Tube pattern: 30	
41	Tube type: Plain	Insert: None		Fin#: #/in	Material: Carbon Steel		
42	Shell Carbon Steel	ID 24.6063	OD 25.3937 in	Shell cover -			
43	Channel or bonnet	Carbon Steel		Channel cover -			
44	Tubesheet-stationary	Carbon Steel	-	Tubesheet-floating -			
45	Floating head cover -			Impingement protection None			
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 30.2	Verti Spacing: c/c 14.1732 in			
47	Baffle-long -	Seal Type		Inlet 29.0738 in			
48	Supports-tube	U-bend	0	Type			
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')			
50	Expansion joint -		Type None				
51	RhoV2-Inlet nozzle 1238	Bundle entrance 1017		Bundle exit 667 lb/(ft-s²)			
52	Gaskets - Shell side -		Tube side	Flat Metal Jacket Fibe			
53	Floating head -						
54	Code requirements	ASME Code Sec VIII Div 1		TEMA class R - refinery service			
55	Weight/Shell	4399.9	Filled with water 6053.9	Bundle 2339 lb			
56	Remarks						
57							
58							

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: LIQ2HX1	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 8.0709 - 47.2441 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 24.6 ft²	Shells/unit 1		Surf/shell(eff.) 24.6 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation	Shell Side		Tube Side		
10	Fluid name	DIESELHO		LIQ2		
11	Fluid quantity, Total lb/h	4379		19338		
12	Vapor (In/Out) lb/h	0	0	0	1	
13	Liquid lb/h	4379	4379	19338	19338	
14	Noncondensable lb/h	0	0	0	0	
15						
16	Temperature (In/Out) °F	338	297.86	248	253.62	
17	Bubble / Dew point °F	/	/	232.86 / 598.17	230.24 / 597.64	
18	Density Vapor/Liquid lb/ft³	/ 40.137	/ 41.179	0.568 / 52.139	0.567 / 51.907	
19	Viscosity cp	/ 0.3199	/ 0.3913	0.0154 / 0.2172	0.0156 / 0.2112	
20	Molecular wt, Vap			11.89	12.24	
21	Molecular wt, NC					
22	Specific heat BTU/(lb-F)	/ 0.6651	/ 0.6421	0.7568 / 1.0528	0.744 / 1.0599	
23	Thermal conductivity BTU/(ft-h-F)	/ 0.062	/ 0.065	0.075 / 0.167	0.074 / 0.166	
24	Latent heat BTU/lb			713.4	474.7	
25	Pressure (abs) psi	14.5	14.33	363	359.9	
26	Velocity (Mean/Max) ft/s	0.24 / 0.25		6.57 / 6.98		
27	Pressure drop, allow./calc. psi	1.6	0.17	7.25	3.1	
28	Fouling resistance (min) ft²-h-F/BTU	0		0	0 Ao based	
29	Heat exchanged 114862 BTU/h			MTD (corrected) 65.15 °F		
30	Transfer rate, Service 71.68	Dirty 84.03		Clean 84.03 BTU/(h-ft²-F)		

31	**CONSTRUCTION OF ONE SHELL**					**Sketch**
32			Shell Side	Tube Side		
33	Design/Vacuum/test pressure psi		43.51 / /	406.11 / /		
34	Design temperature °F		401	401		
35	Number passes per shell		1	4		
36	Corrosion allowance in		0.125	0.125		
37	Connections	In in	1 1 / -	1 1.5 / -		
38	Size/Rating	Out	1 1.25 / -	1 1.5 / -		
39	ID	Intermediate	/ -	/ -		

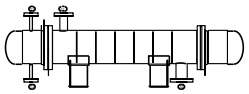


40	Tube #: 34	OD: 0.75	Tks. Average 0.083 in	Length: 47.2441 in	Pitch: 0.9375 in	Tube pattern: 30
41	Tube type: Plain	Insert: None		Fin#: #/in	Material: Carbon Steel	
42	Shell Carbon Steel	ID 8.071	OD 8.625 in	Shell cover -		
43	Channel or bonnet	Carbon Steel		Channel cover -		
44	Tubesheet-stationary	Carbon Steel	-	Tubesheet-floating -		
45	Floating head cover -			Impingement protection None		
46	Baffle-cross Carbon Steel	Type Single segmental	Cut(%d) 43.02	Horiz. Spacing: c/c 5.315 in		
47	Baffle-long -	Seal Type		Inlet 8.8179 in		
48	Supports-tube	U-bend	0	Type		
49	Bypass seal		Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')		
50	Expansion joint -		Type None			
51	RhoV2-Inlet nozzle 1023	Bundle entrance 2		Bundle exit 4	lb/(ft-s²)	
52	Gaskets - Shell side -		Tube side	Flat Metal Jacket Fibe		
53	Floating head -					
54	Code requirements	ASME Code Sec VIII Div 1		TEMA class R - refinery service		
55	Weight/Shell	495.1 Filled with water 580.8		Bundle 158.4 lb		
56	Remarks					
57						
58						

TEMA Sheet

Heat Exchanger Specification Sheet

1	Company:					
2	Location:					
3	Service of Unit:	Our Reference:				
4	Item No.: LUBEHX	Your Reference:				
5	Date:	Rev No.:	Job No.:			
6	Size: 10.1181 - 47.2441 in	Type: BEM	Horizontal	Connected in: 1 parallel	1 series	
7	Surf/unit(eff.) 30.4 ft²	Shells/unit 1		Surf/shell(eff.) 30.4 ft²		
8	**PERFORMANCE OF ONE UNIT**					
9	Fluid allocation	Shell Side		Tube Side		
10	Fluid name	LIQ2WARM		LUBE		
11	Fluid quantity, Total lb/h	19338		18		
12	Vapor (In/Out) lb/h	0	0	0	0	
13	Liquid lb/h	19338	19338	18	18	
14	Noncondensable lb/h	0	0	0	0	
15						
16	Temperature (In/Out) °F	253.62	253.84	662	303.63	
17	Bubble / Dew point °F	232.86 / 598.17	232.42 / 598.12	/	/	
18	Density Vapor/Liquid lb/ft³	0.575 / 51.905	0.575 / 51.896	/ 32.608	/ 42.725	
19	Viscosity cp	0.0156 / 0.2111	0.0156 / 0.2109	/ 0.1558	/ 0.5976	
20	Molecular wt, Vap	12.13	12.17			
21	Molecular wt, NC					
22	Specific heat BTU/(lb-F)	0.7436 / 1.0599	0.7431 / 1.0602	/ 0.8282	/ 0.6359	
23	Thermal conductivity BTU/(ft-h-F)	0.074 / 0.166	0.074 / 0.166	/ 0.043	/ 0.069	
24	Latent heat BTU/lb	403.9	307.4			
25	Pressure (abs) psi	363	362.71	362.59	362.59	
26	Velocity (Mean/Max) ft/s	0.41 / 0.45		0.01 / 0.02		
27	Pressure drop, allow./calc. psi	7.25	0.29	5.08	0	
28	Fouling resistance (min) ft²-h-F/BTU	0		0	0 Ao based	
29	Heat exchanged 4769 BTU/h			MTD (corrected) 178.5 °F		
30	Transfer rate, Service 0.88	Dirty 11.96		Clean 11.96 BTU/(h-ft²-F)		
31	**CONSTRUCTION OF ONE SHELL**			**Sketch**		
32		Shell Side	Tube Side			
33	Design/Vacuum/test pressure psi	406.11 / /	406.11 / /			
34	Design temperature °F	725	725			
35	Number passes per shell	1	8			
36	Corrosion allowance in	0.125	0.125			
37	Connections In in	1 3 / -	1 0.5 / -			
38	Size/Rating Out	1 2 / -	1 0.5 / -			
39	ID Intermediate	1 / -	1 / -			
40	Tube #: 42 OD: 0.75 Tks. Average 0.083 in	Length: 47.2441 in	Pitch: 0.9375 in	Tube pattern: 30		
41	Tube type: Plain	Insert: None	Fin#: #/in	Material: Carbon Steel		
42	Shell Carbon Steel ID 10.136 OD 10.75 in		Shell cover -			
43	Channel or bonnet Carbon Steel		Channel cover -			
44	Tubesheet-stationary Carbon Steel -		Tubesheet-floating -			
45	Floating head cover -		Impingement protection None			
46	Baffle-cross Carbon Steel Type Single segmental	Cut(%d) 43.22	Verti Spacing: c/c 5.9055 in			
47	Baffle-long - Seal Type		Inlet 7.3415 in			
48	Supports-tube U-bend 0		Type			
49	Bypass seal	Tube-tubesheet joint	Expanded only (2 grooves)(App.A 'i')			
50	Expansion joint -	Type None				
51	RhoV2-Inlet nozzle 211	Bundle entrance 114	Bundle exit 56 lb/(ft-s²)			
52	Gaskets - Shell side -	Tube side	Flat Metal Jacket Fibe			
53	Floating head -					
54	Code requirements ASME Code Sec VIII Div 1	TEMA class R - refinery service				
55	Weight/Shell 626 Filled with water 760.4	Bundle 213.2 lb				
56	Remarks					
57						
58						



Appendix C

Safety Data Sheets (SDS)

SAFETY DATA SHEET

Version 3.10
Revision Date 09/27/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Carbon monoxide

Product Number : 295116
Brand : Aldrich
Index-No. : 006-001-00-2

CAS-No. : 630-08-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable gases (Category 1), H220
Gases under pressure (Compressed gas), H280
Acute toxicity, Inhalation (Category 3), H331
Reproductive toxicity (Category 1A), H360
Specific target organ toxicity - repeated exposure, Inhalation (Category 1), H372

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
H331	Toxic if inhaled.
H360	May damage fertility or the unborn child.
H372	Causes damage to organs through prolonged or repeated exposure if inhaled.

Precautionary statement(s)

P201	Obtain special instructions before use.
P202	Do not handle until all safety precautions have been read and

	understood.
P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P260	Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P270	Do not eat, drink or smoke when using this product.
P271	Use only outdoors or in a well-ventilated area.
P281	Use personal protective equipment as required.
P304 + P340 + P311	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/ physician.
P308 + P313	IF exposed or concerned: Get medical advice/ attention.
P377	Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381	Eliminate all ignition sources if safe to do so.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	CO
Molecular weight	:	28.01 g/mol
CAS-No.	:	630-08-0
EC-No.	:	211-128-3
Index-No.	:	006-001-00-2

Hazardous components

Component	Classification	Concentration
Carbon monoxide		
	Flam. Gas 1; Press. Gas Compr. Gas; Acute Tox. 3; Repr. 1A; STOT RE 1; H220, H280, H331, H360, H372	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Take victim immediately to hospital. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Carbon monoxide	630-08-0	TWA	50.000000 ppm 55.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
	Remarks	The value in mg/m3 is approximate.		
		TWA	25 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Carboxyhemoglobinemia Substances for which there is a Biological Exposure Index or Indices (see BEI® section)		

		TWA	25.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Carboxyhemoglobinemia Substances for which there is a Biological Exposure Index or Indices (see BEI® section)		
		TWA	35.000000 ppm 40.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	200.000000 ppm 229.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	200 ppm	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		PEL	25 ppm 29 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

Biological occupational exposure limits

Component	CAS-No.	Parameters	Value	Biological specimen	Basis
Carbon monoxide	630-08-0	Carboxyhemoglobin	3.500 %	In blood	ACGIH - Biological Exposure Indices (BEI)
	Remarks	End of shift (As soon as possible after exposure ceases)			
		Carbon monoxide	20ppm	In end-exhaled air	ACGIH - Biological Exposure Indices (BEI)
		End of shift (As soon as possible after exposure ceases)			

8.2 Exposure controls

Appropriate engineering controls
Avoid contact with skin, eyes and clothing. Wash hands before breaks and immediately after handling the product.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash contact
Material: Chloroprene
Minimum layer thickness: 0.6 mm
Break through time: 30 min
Material tested:Camapren® (KCL 722 / Aldrich Z677493, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Compressed gas
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -205 °C (-337 °F) - lit.
f)	Initial boiling point and boiling range	-191.5 °C (-312.7 °F) - lit.
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 74 %(V) Lower explosion limit: 12.5 %(V)
k)	Vapour pressure	No data available
l)	Vapour density	0.97 - (Air = 1.0)
m)	Relative density	No data available
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	0.97 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Sodium/sodium oxides, Potassium, Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LC50 Inhalation - Rat - 4 h - 1807 ppm

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
Known human reproductive toxicant

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
Inhalation - Causes damage to organs through prolonged or repeated exposure.

Aspiration hazard
No data available

Additional Information
RTECS: FG3500000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1016 Class: 2.3 (2.1)
Proper shipping name: Carbon monoxide, compressed
Reportable Quantity (RQ):
Poison Inhalation Hazard: Hazard zone D

IMDG
UN number: 1016 Class: 2.3 (2.1) EMS-No: F-D, S-U
Proper shipping name: CARBON MONOXIDE, COMPRESSED

IATA
UN number: 1016 Class: 2.3 (2.1)
Proper shipping name: Carbon monoxide, compressed
IATA Passenger: Not permitted for transport
IATA Cargo: Not permitted for transport

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Sudden Release of Pressure Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Carbon monoxide	630-08-0	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Carbon monoxide	630-08-0	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Carbon monoxide	630-08-0	1993-04-24

California Prop. 65 Components

	CAS-No.	Revision Date
WARNING: This product contains a chemical known to the State of California to cause birth defects or other reproductive harm. Carbon monoxide	630-08-0	2007-09-28
WARNING: This product contains a chemical known to the State of California to cause birth defects or other reproductive harm. Carbon monoxide	630-08-0	2007-09-28

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Acute Tox.	Acute toxicity
Flam. Gas	Flammable gases
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
H331	Toxic if inhaled.
H360	May damage fertility or the unborn child.
H372	Causes damage to organs through prolonged or repeated exposure if inhaled.
Press. Gas	Gases under pressure
Repr.	Reproductive toxicity
STOT RE	Specific target organ toxicity - repeated exposure

HMIS Rating

Health hazard:	3
Chronic Health Hazard:	*
Flammability:	4
Physical Hazard	0

NFPA Rating

Health hazard:	3
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.10 Revision Date: 09/27/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.12
Revision Date 09/27/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Carbon dioxide

Product Number : 295108
Brand : Aldrich

CAS-No. : 124-38-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Gases under pressure (Liquefied gas), H280
Simple Asphyxiant,

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Warning

Hazard statement(s)
H280 Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statement(s)
P410 + P403 Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : CO_2
Molecular weight : 44.01 g/mol
CAS-No. : 124-38-9

EC-No. : 204-696-9

Hazardous components

Component	Classification	Concentration
Carbon dioxide		
	Press. Gas Liquefied gas; SA ; H280,	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure. Avoid heating above: 50°C

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Carbon dioxide	124-38-9	TWA	5,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Asphyxia		
		TWA	5,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Asphyxia		
		STEL	30,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Asphyxia		
		STEL	30,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Asphyxia		
		TWA	5,000.000000 ppm 9,000.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	5,000.000000 ppm 9,000.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		Normal constituent of air (about 300 ppm).		
		ST	30,000.000000 ppm 54,000.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		Normal constituent of air (about 300 ppm).		
		TWA	5,000 ppm 9,000 mg/m3	USA. NIOSH Recommended Exposure Limits
		Normal constituent of air (about 300 ppm).		
		ST	30,000 ppm 54,000 mg/m3	USA. NIOSH Recommended Exposure Limits
		Normal constituent of air (about 300 ppm).		
		TWA	5,000 ppm 9,000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		

		PEL	5,000 ppm 9,000 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		STEL	30,000 ppm 54,000 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash contact
Material: Chloroprene
Minimum layer thickness: 0.6 mm
Break through time: 30 min
Material tested:Camapren® (KCL 722 / Aldrich Z677493, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Liquefied gas
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing	Melting point/range: -78.5 °C (-109.3 °F) - lit.

	point	
f)	Initial boiling point and boiling range	No data available
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	57,249 hPa (42,940 mmHg) at 20 °C (68 °F)
l)	Vapour density	1.52 - (Air = 1.0)
m)	Relative density	No data available
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Sublimation point	-78.49 °C
Relative vapour density	1.52 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
No data available

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: FF6400000

Nausea, Dizziness, Headache, Low to medium concentrations of carbon dioxide can:, affect regulation of blood circulation, affect the acidity of body fluids, respiratory difficulties, At high concentrations:, Breathing difficulties, Increased pulse rate, change in body acidity, Very high concentrations can cause:, Unconsciousness, death

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1013 Class: 2.2
Proper shipping name: Carbon dioxide
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
UN number: 1013 Class: 2.2 EMS-No: F-C, S-V
Proper shipping name: CARBON DIOXIDE

IATA
UN number: 1013 Class: 2.2
Proper shipping name: Carbon dioxide

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Carbon dioxide	124-38-9	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Carbon dioxide	124-38-9	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Carbon dioxide	124-38-9	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

	May displace oxygen and cause rapid suffocation.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure
SA	Simple Asphyxiant

HMIS Rating
Health hazard: 0
Chronic Health Hazard:

Flammability:	1
Physical Hazard	1

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.12 Revision Date: 09/27/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.11
Revision Date 09/27/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Hydrogen

Product Number : 295396
Brand : Aldrich
Index-No. : 001-001-00-9

CAS-No. : 1333-74-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable gases (Category 1), H220
Gases under pressure (Compressed gas), H280
Simple Asphyxiant,

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated. May displace oxygen and cause rapid suffocation.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P377	Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381	Eliminate all ignition sources if safe to do so.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	H_2
Molecular weight	:	2.02 g/mol
CAS-No.	:	1333-74-0
EC-No.	:	215-605-7
Index-No.	:	001-001-00-9

Hazardous components

Component	Classification	Concentration
Hydrogen		
	Flam. Gas 1; Press. Gas Compr. Gas; SA ; H220, H280,	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

No data available

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

	Remarks	Asphyxia See Notice of Intended Changes (NIC) Simple asphyxiant; see discussion covering Minimal Oxygen Content found in the 'Definitions and Notations' section following the NIC tables
		See Appendix F: Minimal Oxygen Content Asphyxia 2015 Adoption Simple asphyxiant; see discussion covering Minimal Oxygen Content found in the 'Definitions and Notations' section following the NIC tables

Hazardous components without workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Splash contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 120 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Compressed gas Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -259.2 °C (-434.6 °F) - lit.
f)	Initial boiling point and boiling range	-252.8 °C (-423.0 °F) - lit.
g)	Flash point	< -150 °C (< -238 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 74.2 %(V) Lower explosion limit: 4 %(V)
k)	Vapour pressure	No data available
l)	Vapour density	0.08
m)	Relative density	No data available
n)	Water solubility	0.00196 g/l at 0 °C (32 °F)
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition	No data available

temperature

q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	0.08

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: MW8900000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Contact a licensed professional waste disposal service to dispose of this material. Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1049 Class: 2.1
Proper shipping name: Hydrogen, compressed
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
UN number: 1049 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: HYDROGEN, COMPRESSED

IATA
UN number: 1049 Class: 2.1
Proper shipping name: Hydrogen, compressed
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Hydrogen	1333-74-0	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Hydrogen	1333-74-0	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Hydrogen	1333-74-0	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

	May displace oxygen and cause rapid suffocation.
Flam. Gas	Flammable gases
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure
SA	Simple Asphyxiant

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	4
Physical Hazard	3

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.11 Revision Date: 09/27/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.2
Revision Date 02/24/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Water

Product Number : W4502
Brand : Sigma
REACH No. : A registration number is not available for this substance as the substance or its uses are exempted from registration, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.
CAS-No. : 7732-18-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : H_2O
Molecular Weight : 18.02 g/mol
CAS-No. : 7732-18-5
EC-No. : 231-791-2

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If not breathing give artificial respiration

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.

5.2 Special hazards arising from the substance or mixture
no data available

5.3 Advice for firefighters
no data available

5.4 Further information
The product itself does not burn.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
For personal protection see section 8.

6.2 Environmental precautions
no data available

6.3 Methods and materials for containment and cleaning up
Wipe up with absorbent material (e.g. cloth, fleece).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
No special storage conditions required.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice.

Personal protective equipment

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min

Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Respiratory protection
No special protective equipment required.

Control of environmental exposure
Prevent product from entering drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: colourless
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	6.0 - 8.0 at 25 °C (77 °F)
e)	Melting point/freezing point	0.0 °C (32.0 °F)
f)	Initial boiling point and boiling range	100 °C (212 °F) - lit.
g)	Flash point	not applicable
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	1.000 g/cm3 at 3.98 °C (39.16 °F)
n)	Water solubility	completely miscible
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
no data available

10.6 Hazardous decomposition products
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: ZC0110000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
not applicable

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Taking into account local regulations the product may be disposed of as waste water after neutralisation.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

REACH No. : A registration number is not available for this substance as the substance or its uses are exempted from registration, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Water	7732-18-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Water	7732-18-5	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.2 Revision Date: 02/24/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.9
Revision Date 05/27/2016
Print Date 04/05/2019

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Methane

Product Number : 463035
Brand : Aldrich
Index-No. : 601-001-00-4

CAS-No. : 74-82-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable gases (Category 1), H220
Gases under pressure (Compressed gas), H280
Simple Asphyxiant,

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H220 Extremely flammable gas.
H280 Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P377 Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381 Eliminate all ignition sources if safe to do so.
P410 + P403 Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	CH_4
Molecular weight	:	16.04 g/mol
CAS-No.	:	74-82-8
EC-No.	:	200-812-7
Index-No.	:	601-001-00-4

Hazardous components

Component	Classification	Concentration
Methane		
	Flam. Gas 1; Press. Gas Compr. Gas; SA ; H220, H280,	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

No data available

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.

For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.
Storage class (TRGS 510): Gases

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Methane	74-82-8	TWA	1,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Cardiac sensitization		
		See Appendix F: Minimal Oxygen Content Asphyxia 2015 Adoption		
		TWA	0.100000 mg/m3	USA. NIOSH Recommended Exposure Limits
		'Ca' in the presence of formaldehyde, acetaldehyde, or malonaldehyde. See Appendices A & C (Aldehydes).		
		TWA	0.100000 mg/m3	USA. NIOSH Recommended Exposure Limits
		'Ca' in the presence of formaldehyde, acetaldehyde, or malonaldehyde. See Appendices A & C (Aldehydes).		
		See Appendix F: Minimal Oxygen Content Asphyxia		
		TWA	0.1 mg/m3	USA. NIOSH Recommended Exposure Limits
		'Ca' in the presence of formaldehyde, acetaldehyde, or malonaldehyde. See Appendices A & C (Aldehydes).		

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested:Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: gaseous Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -183 °C (-297 °F) - lit.
f)	Initial boiling point and boiling range	-161 °C (-258 °F) - lit.
g)	Flash point	-188 °C (-306 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower	Upper explosion limit: 15 %(V)

	flammability or explosive limits	Lower explosion limit: 5 %(V)
k)	Vapour pressure	No data available
l)	Vapour density	0.55 - (Air = 1.0)
m)	Relative density	0.716 g/cm3 at 25 °C (77 °F)
n)	Water solubility	3.5 g/l at 17 °C (63 °F)
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	0.55 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: PA1490000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1971 Class: 2.1

Proper shipping name: Methane, compressed
Reportable Quantity (RQ):

Poison Inhalation Hazard: No

IMDG
UN number: 1971 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: METHANE, COMPRESSED

IATA
UN number: 1971 Class: 2.1
Proper shipping name: Methane, compressed
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Methane	74-82-8	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Methane	74-82-8	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Methane	74-82-8	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

	May displace oxygen and cause rapid suffocation.
Flam. Gas	Flammable gases
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure
SA	Simple Asphyxiant

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	4
Physical Hazard	3

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.9 Revision Date: 05/27/2016 Print Date: 04/05/2019

SAFETY DATA SHEET

Version 3.7
Revision Date 06/02/2016
Print Date 10/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name	:	Ethane
Product Number	:	539775
Brand	:	Aldrich
Index-No.	:	601-002-00-X
CAS-No.	:	74-84-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #	:	+1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable gases (Category 1), H220
Gases under pressure (Liquefied gas), H280
Simple Asphyxiant,

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated. May displace oxygen and cause rapid suffocation.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P377	Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381	Eliminate all ignition sources if safe to do so.
P410 + P403	Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	C_2H_6
Molecular weight	:	30.07 g/mol
CAS-No.	:	74-84-0
EC-No.	:	200-814-8
Index-No.	:	601-002-00-X

Hazardous components

Component	Classification	Concentration
Ethane		
	Flam. Gas 1; Press. Gas Liquefied gas; SA ; H220, H280,	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

No data available

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.

For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.
Storage class (TRGS 510): Gases

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Ethane	74-84-0	TWA	1,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Cardiac sensitization		
		See Appendix F: Minimal Oxygen Content Asphyxia 2015 Adoption		
		TWA	0.100000 mg/m3	USA. NIOSH Recommended Exposure Limits
		'Ca' in the presence of formaldehyde, acetaldehyde, or malonaldehyde. See Appendices A & C (Aldehydes).		
		TWA	0.100000 mg/m3	USA. NIOSH Recommended Exposure Limits
		'Ca' in the presence of formaldehyde, acetaldehyde, or malonaldehyde. See Appendices A & C (Aldehydes).		
		See Appendix F: Minimal Oxygen Content Asphyxia		
		TWA	0.1 mg/m3	USA. NIOSH Recommended Exposure Limits
		'Ca' in the presence of formaldehyde, acetaldehyde, or malonaldehyde. See Appendices A & C (Aldehydes).		

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested:Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: gaseous
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -172 °C (-278 °F) - lit.
f)	Initial boiling point and boiling range	-88 °C (-126 °F) - lit.
g)	Flash point	-135 °C (-211 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	Upper explosion limit: 13 %(V) Lower explosion limit: 2.9 %(V)

	explosive limits	
k)	Vapour pressure	38,453 hPa (28,842 mmHg) at 21.1 °C (70.0 °F)
l)	Vapour density	1.04 - (Air = 1.0)
m)	Relative density	0.362 g/cm3 at 20 °C (68 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	1.04 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: KH3800000

narcosis, To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1035 Class: 2.1

Proper shipping name: Ethane
Reportable Quantity (RQ):

Poison Inhalation Hazard: No

IMDG
UN number: 1035 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: ETHANE

IATA
UN number: 1035 Class: 2.1
Proper shipping name: Ethane
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Ethane	74-84-0	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Ethane	74-84-0	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Ethane	74-84-0	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

	May displace oxygen and cause rapid suffocation.
Flam. Gas	Flammable gases
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure
SA	Simple Asphyxiant

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	4
Physical Hazard	3

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.7 Revision Date: 06/02/2016 Print Date: 10/19/2018

SAFETY DATA SHEET

Version 3.8
Revision Date 06/02/2016
Print Date 10/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Propane

Product Number : 536172
Brand : Aldrich
Index-No. : 601-003-00-5

CAS-No. : 74-98-6

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable gases (Category 1), H220
Gases under pressure (Liquefied gas), H280
Simple Asphyxiant,

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H220 Extremely flammable gas.
H280 Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P377 Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381 Eliminate all ignition sources if safe to do so.
P410 + P403 Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	C_3H_8
Molecular weight	:	44.10 g/mol
CAS-No.	:	74-98-6
EC-No.	:	200-827-9
Index-No.	:	601-003-00-5

Hazardous components

Component	Classification	Concentration
Propane		
	Flam. Gas 1; Press. Gas Liquefied gas; SA ; H220, H280,	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

No data available

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.

For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Propane	74-98-6	TWA	1,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Cardiac sensitization		
		TWA	1,000.000000 ppm 1,800.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	1,000.000000 ppm 1,800.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		See Appendix F: Minimal Oxygen Content Asphyxia 2015 Adoption		
		See Appendix F: Minimal Oxygen Content Asphyxia		
		PEL	1,000 ppm 1,800 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested:Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Liquefied gas
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -188 °C (-306 °F) - lit.
f)	Initial boiling point and boiling range	-42.1 °C (-43.8 °F) - lit.
g)	Flash point	-104 °C (-155 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	Upper explosion limit: 9.5 %(V) Lower explosion limit: 2.1 %(V)

	explosive limits	
k)	Vapour pressure	13,096 hPa (9,823 mmHg) at 37.7 °C (99.9 °F) 8,531.6 hPa (6,399.2 mmHg) at 21.1 °C (70.0 °F)
l)	Vapour density	1.52 - (Air = 1.0)
m)	Relative density	0.564 g/mL at 20 °C (68 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	1.52 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: TX2275000

Dizziness, Drowsiness, Unconsciousness
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1978 Class: 2.1
Proper shipping name: Propane

Poison Inhalation Hazard: No

IMDG
UN number: 1978 Class: 2.1 EMS-No: F-D, S-U

Proper shipping name: PROPANE

IATA
UN number: 1978 Class: 2.1
Proper shipping name: Propane
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Sudden Release of Pressure Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Propane	74-98-6	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Propane	74-98-6	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Propane	74-98-6	1993-04-24

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

	May displace oxygen and cause rapid suffocation.
Flam. Gas	Flammable gases
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure
SA	Simple Asphyxiant

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	4
Physical Hazard	3

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.8 Revision Date: 06/02/2016 Print Date: 10/19/2018

SAFETY DATA SHEET

Version 3.10
Revision Date 05/24/2016
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Butane

Product Number : 494402
Brand : Aldrich
Index-No. : 601-004-00-0

CAS-No. : 106-97-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable gases (Category 1), H220
Gases under pressure (Liquefied gas), H280
Simple Asphyxiant,

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H220 Extremely flammable gas.
H280 Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P377 Leaking gas fire: Do not extinguish, unless leak can be stopped safely.
P381 Eliminate all ignition sources if safe to do so.
P410 + P403 Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	C_4H_{10}
Molecular weight	:	58.12 g/mol
CAS-No.	:	106-97-8
EC-No.	:	203-448-7
Index-No.	:	601-004-00-0

Hazardous components

Component	Classification	Concentration
Butane		
	Flam. Gas 1; Press. Gas Liquefied gas; SA ; H220, H280,	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

No data available

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.

For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.
Storage class (TRGS 510): Gases

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Butane	106-97-8	TWA	1,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Cardiac sensitization		
		TWA	800.000000 ppm 1,900.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		Also see specific listing for Isobutane.		
		STEL	1,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment 2015 Adoption		
		TWA	1,000.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment Cardiac sensitization varies		
		TWA	800 ppm 1,900 mg/m3	USA. NIOSH Recommended Exposure Limits
		Also see specific listing for Isobutane.		
		STEL	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment		

		PEL	800 ppm 1,900 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested:Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 60 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: gaseous
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -138 °C (-216 °F) - lit.
f)	Initial boiling point and	-0.5 °C (31.1 °F) - lit.

	boiling range	
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 8.4 %(V) Lower explosion limit: 1.8 %(V)
k)	Vapour pressure	2,426 hPa (1,820 mmHg) at 25 °C (77 °F) 3,556.67 hPa (2,667.72 mmHg) at 37.7 °C (99.9 °F)
l)	Vapour density	2.33
m)	Relative density	0.579 g/mL at 20 °C (68 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	log Pow: 2.89
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density 2.33

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
No data available

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

LC50 Inhalation - Rat - 4 h - 658,000 mg/m3

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: EJ4200000

Central nervous system depression, giddiness, Shortness of breath, narcosis, Dermal contact with rapidly evaporating liquid could result in freezing of the tissues or frostbite., Exposure can cause numbness, tingling, and weakness in extremities., Cyanosis, Pulmonary edema. Effects may be delayed., Abdominal pain, Nausea, Vomiting

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1011 Class: 2.1
Proper shipping name: Butane
Reportable Quantity (RQ):

Poison Inhalation Hazard: No

IMDG
UN number: 1011 Class: 2.1 EMS-No: F-D, S-U
Proper shipping name: BUTANE

IATA
UN number: 1011 Class: 2.1
Proper shipping name: Butane
IATA Passenger: Not permitted for transport

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Butane	106-97-8	1994-04-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Butane	106-97-8	1994-04-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Butane	106-97-8	1994-04-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

May displace oxygen and cause rapid suffocation.

Flam. Gas	Flammable gases
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure
SA	Simple Asphyxiant

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	*
Flammability:	4
Physical Hazard	3

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.10 Revision Date: 05/24/2016 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.9
Revision Date 06/08/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Pentane

Product Number : 236705
Brand : Sigma-Aldrich
Index-No. : 601-006-00-1

CAS-No. : 109-66-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 1), H224
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 2), H401
Chronic aquatic toxicity (Category 2), H411

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H224	Extremely flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H336	May cause drowsiness or dizziness.
H411	Toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.

P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353	IF ON SKIN (or hair): Remove/ Take off immediately all contaminated clothing. Rinse skin with water/ shower.
P304 + P340 + P312	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/ physician if you feel unwell.
P331	Do NOT induce vomiting.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam for extinction.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Repeated exposure may cause skin dryness or cracking.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	C_5H_{12}
Molecular weight	:	72.15 g/mol
CAS-No.	:	109-66-0
EC-No.	:	203-692-4
Index-No.	:	601-006-00-1
Registration number	:	01-2119459286-30-XXXX

Hazardous components

Component	Classification	Concentration
n-Pentane		
	Flam. Liq. 1; STOT SE 3; Asp. Tox. 1; Aquatic Acute 2; Aquatic Chronic 2; H224, H304, H336, H411	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

Refrigerate before opening.
Storage class (TRGS 510): 3: Flammable liquids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
n-Pentane	109-66-0	TWA	120 ppm 350 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	610 ppm 1,800 mg/m3	USA. NIOSH Recommended Exposure Limits
	Remarks	15 minute ceiling value		
		TWA	1,000 ppm 2,950 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		PEL	600 ppm 1,800 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		TWA	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		narcosis respiratory tract irritation		

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid, clear Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -130 °C (-202 °F) - lit.
f)	Initial boiling point and boiling range	35 - 36 °C (95 - 97 °F) - lit.
g)	Flash point	-49.0 °C (-56.2 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 8.3 %(V) Lower explosion limit: 1.4 %(V)
k)	Vapour pressure	579.0 hPa (434.3 mmHg) at 20.0 °C (68.0 °F) 1,859.7 hPa (1,394.9 mmHg) at 55.0 °C (131.0 °F)
l)	Vapour density	No data available
m)	Relative density	0.626 g/cm3 at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	log Pow: 3.39
p)	Auto-ignition temperature	260.0 °C (500.0 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	Not explosive
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Mouse - 5,000 mg/kg

LC50 Inhalation - Rat - 4 h - 364,000 mg/m3

LD50 Dermal - Rabbit - 3,000 mg/kg

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
Ames test
S. typhimurium
Result: negative

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
May cause drowsiness or dizziness.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information
RTECS: RZ9450000

Contact with eyes can cause:, Redness, Blurred vision, Provokes tears., Prolonged or repeated contact with skin may cause:, defatting, Dermatitis, Central nervous system depression, Damage to the lungs.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to daphnia and other aquatic invertebrates	EC50 - Daphnia magna (Water flea) - 9.74 mg/l - 48 h

12.2 Persistence and degradability

Biodegradability	Biotic/Aerobic - Exposure time 192 h Result: 70 % - Readily biodegradable.

12.3 Bioaccumulative potential

No data available

12.4 Mobility in soil

No data available

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Toxic to aquatic life with long lasting effects.

Avoid release to the environment. Do not empty into drains.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1265 Class: 3 Packing group: II
Proper shipping name: Pentanes
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
UN number: 1265 Class: 3 Packing group: II EMS-No: F-E, S-D
Proper shipping name: PENTANES
Marine pollutant:yes

IATA
UN number: 1265 Class: 3 Packing group: II
Proper shipping name: Pentanes

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
n-Pentane	109-66-0	1993-02-16

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
n-Pentane	109-66-0	1993-02-16

New Jersey Right To Know Components

	CAS-No.	Revision Date
n-Pentane	109-66-0	1993-02-16

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H224	Extremely flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H336	May cause drowsiness or dizziness.
H401	Toxic to aquatic life.
H411	Toxic to aquatic life with long lasting effects.
STOT SE	Specific target organ toxicity - single exposure

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	*
Flammability:	4
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.9 Revision Date: 06/08/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.7
Revision Date 06/08/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Hexane

Product Number : 296090
Brand : Sigma-Aldrich
Index-No. : 601-037-00-0

CAS-No. : 110-54-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 2), H225
Skin irritation (Category 2), H315
Reproductive toxicity (Category 2), H361
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Specific target organ toxicity - repeated exposure, Oral (Category 2), Nervous system, H373
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 2), H401
Chronic aquatic toxicity (Category 2), H411

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H361	Suspected of damaging fertility or the unborn child.
H373	May cause damage to organs (Nervous system) through prolonged or repeated exposure if swallowed.

H411	Toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P201	Obtain special instructions before use.
P202	Do not handle until all safety precautions have been read and understood.
P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P260	Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ protective clothing/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P312	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.
P308 + P313	IF exposed or concerned: Get medical advice/ attention.
P331	Do NOT induce vomiting.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms	:	n-Hexane
Formula	:	C_6H_{14}
Molecular weight	:	86.18 g/mol
CAS-No.	:	110-54-3
EC-No.	:	203-777-6
Index-No.	:	601-037-00-0
Registration number	:	01-2119480412-44-XXXX

Hazardous components

Component	Classification	Concentration
n-Hexane		
	Flam. Liq. 2; Skin Irrit. 2; Repr. 2; STOT SE 3; STOT RE 2; Asp. Tox. 1; Aquatic Acute 2; Aquatic Chronic 2; H225, H304, H315, H336, H361f, H373, H411	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Flash back possible over considerable distance.Container explosion may occur under fire conditions.Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.

For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.
Storage class (TRGS 510): 3: Flammable liquids

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
n-Hexane	110-54-3	TWA	50 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Eye irritation Peripheral neuropathy Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Danger of cutaneous absorption		
		TWA	50 ppm 180 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	500 ppm 1,800 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		PEL	50 ppm 180 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		Skin		

Biological occupational exposure limits

Component	CAS-No.	Parameters	Value	Biological specimen	Basis
	-	2,5-Hexanedione	0.4 mg/l	Urine	ACGIH - Biological Exposure Indices (BEI)
	Remarks	End of shift at end of workweek			

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.2 mm
Break through time: 59 min
Material tested:Dermatril® P (KCL 743 / Aldrich Z677388, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	7.0
e)	Melting point/freezing point	Melting point/range: -95 °C (-139 °F)
f)	Initial boiling point and boiling range	69 °C (156 °F)
g)	Flash point	-26.0 °C (-14.8 °F) - closed cup
h)	Evaporation rate	15.8
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 7.7 %(V) Lower explosion limit: 1.2 %(V)
k)	Vapour pressure	341.3 hPa (256.0 mmHg) at 37.7 °C (99.9 °F) 176.0 hPa (132.0 mmHg) at 20.0 °C (68.0 °F)
l)	Vapour density	No data available
m)	Relative density	0.659 g/mL at 25 °C (77 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	log Pow: 3.90 - 4.11
p)	Auto-ignition temperature	234.0 °C (453.2 °F)

q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Exposure to moisture may affect product quality.
Heat, flames and sparks.

10.5 Incompatible materials
Oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Carbon oxides
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity

LD50 Oral - Rat - male and female - 16,000 mg/kg
(OECD Test Guideline 401)

LC50 Inhalation - Rat - 4 h - 172 mg/l
Remarks: (RTECS)

LD50 Dermal - Rabbit - > 2,000 mg/kg
Remarks: (ECHA)

Skin corrosion/irritation
Serious eye damage/eye irritation
Respiratory or skin sensitisation
Germ cell mutagenicity
In vitro mammalian cell gene mutation test
Mouse lymphoma test
Result: Positive results were obtained in some in vitro tests.

Ames test
Salmonella typhimurium
Result: negative

Result: negative
(National Toxicology Program)

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
Suspected of damaging the unborn child.

Suspected of damaging fertility.

Specific target organ toxicity - single exposure
May cause drowsiness or dizziness. - Central nervous system

Specific target organ toxicity - repeated exposure
Inhalation - May cause damage to organs through prolonged or repeated exposure. - Nervous system

Aspiration hazard
Aspiration hazard, Aspiration may cause pulmonary oedema and pneumonitis.

Additional Information
RTECS: MN9275000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
Drowsiness, irritant effects, somnolence
narcosis, Nausea, Tiredness, CNS disorders, paralysis symptoms
Risk of corneal clouding.
It generally applies for aliphatic hydrocarbons with 6 - 18 carbon atoms that they may cause pneumonia, in some cases also pulmonary oedema, upon direct inhalation, i.e. in conditions that can occur only in very special circumstances (nebulizations, spraying, inhalation of aerosols and similar). After absorption of very large quantities: narcosis.

Testes. - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Pimephales promelas (fathead minnow) - 2.5 mg/l - 96 h Remarks: (ECOTOX Database)
Toxicity to daphnia and other aquatic invertebrates	EC50 - Daphnia magna (Water flea) - 2.1 mg/l - 48 h Remarks: (Lit.)

12.2 Persistence and degradability

12.3 Bioaccumulative potential

12.4 Mobility in soil

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Toxic to aquatic life with long lasting effects.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1208 Class: 3 Packing group: II
Proper shipping name: Hexanes
Reportable Quantity (RQ): 5000 lbs
Poison Inhalation Hazard: No

IMDG
UN number: 1208 Class: 3 Packing group: II EMS-No: F-E, S-D
Proper shipping name: HEXANES
Marine pollutant:yes

IATA
UN number: 1208 Class: 3 Packing group: II
Proper shipping name: Hexanes

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

Massachusetts Right To Know Components

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H361	Suspected of damaging fertility or the unborn child.
H361f	Suspected of damaging fertility.
H373	May cause damage to organs (/$/*_2ORG_REP_ORA/$/) through prolonged or repeated exposure if swallowed.
H401	Toxic to aquatic life.
H411	Toxic to aquatic life with long lasting effects.

HMIS Rating
Health hazard: 2

Chronic Health Hazard:	*
Flammability:	3
Physical Hazard	0

NFPA Rating

Health hazard:	2
Fire Hazard:	3
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.7 Revision Date: 06/08/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.12
Revision Date 07/26/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Heptane

Product Number : 246654
Brand : Sigma-Aldrich
Index-No. : 601-008-00-2

CAS-No. : 142-82-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 2), H225
Skin irritation (Category 2), H315
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H410	Very toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.

P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P312	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.
P331	Do NOT induce vomiting.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	C_7H_{16}
Molecular weight	:	100.20 g/mol
CAS-No.	:	142-82-5
EC-No.	:	205-563-8
Index-No.	:	601-008-00-2
Registration number	:	01-2119457603-38-XXXX

Hazardous components

Component	Classification	Concentration
Heptane		
	Flam. Liq. 2; Skin Irrit. 2; STOT SE 3; Asp. Tox. 1; Aquatic Acute 1; Aquatic Chronic 1; H225, H304, H315, H336, H410	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Dry powder Dry sand

Unsuitable extinguishing media
Do NOT use water jet.

5.2 Special hazards arising from the substance or mixture
Flash back possible over considerable distance.

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
In case of fire: Evacuate area. Fight fire remotely due to the risk of explosion.Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with non-combustible absorbent material, (e.g. sand, earth, diatomaceous earth, vermiculite) and place in container for disposal according to local / national regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Store under inert gas. Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.
Storage class (TRGS 510): 3: Flammable liquids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Heptane	142-82-5	TWA	85 ppm 350 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	440 ppm 1,800 mg/m3	USA. NIOSH Recommended Exposure Limits
	Remarks	15 minute ceiling value		
		TWA	500 ppm 2,000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		PEL	400 ppm 1,600 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		STEL	500 ppm 2,000 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		TWA	400 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment Upper Respiratory Tract irritation		
		STEL	500 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment Upper Respiratory Tract irritation		

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.2 mm
Break through time: 65 min
Material tested:Dermatril® P (KCL 743 / Aldrich Z677388, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an

industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -91 °C (-132 °F)
f)	Initial boiling point and boiling range	98 °C (208 °F)
g)	Flash point	22 °C (72 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 7 %(V) Lower explosion limit: 1.1 %(V)
k)	Vapour pressure	110.7 hPa (83.0 mmHg) at 37.7 °C (99.9 °F) 53.3 hPa (40.0 mmHg) at 20.0 °C (68.0 °F)
l)	Vapour density	No data available
m)	Relative density	0.684 g/mL at 25 °C (77 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	log Pow: > 3.000
p)	Auto-ignition temperature	223.0 °C (433.4 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Carbon oxides
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

LC50 Inhalation - Rat - 4 h - 103,000 mg/m3

Inhalation: Irritating to respiratory system.

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

This product is or contains a component that is not classifiable as to its carcinogenicity based on its IARC, ACGIH, NTP, or EPA classification.

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
May cause drowsiness or dizziness.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information
RTECS: MI7700000

Prolonged or repeated exposure to skin causes defatting and dermatitis., Central nervous system depression, narcosis, Damage to the lungs.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Carassius auratus (goldfish) - 4 mg/l - 24.0 h
	LC50 - Tilapia mossambica - 375 mg/l - 96.0 h
Toxicity to daphnia and other aquatic invertebrates	EC50 - Daphnia magna (Water flea) - 1.50 mg/l - 48 h

12.2 Persistence and degradability

Ratio BOD/ThBOD	3.5 %

12.3 Bioaccumulative potential
Indication of bioaccumulation.

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
Very toxic to aquatic life with long lasting effects.
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.

Do not empty into drains. Avoid release to the environment.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1206 Class: 3 Packing group: II
Proper shipping name: Heptanes
Reportable Quantity (RQ): Marine pollutant:yes
Poison Inhalation Hazard: No

IMDG
UN number: 1206 Class: 3 Packing group: II EMS-No: F-E, S-D

Proper shipping name: HEPTANES
Marine pollutant:yes Marine pollutant: yes

IATA
UN number: 1206 Class: 3 Packing group: II
Proper shipping name: Heptanes

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Heptane	142-82-5	1993-02-16

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Heptane	142-82-5	1993-02-16

	CAS-No.	Revision Date
Heptane	142-82-5	1993-02-16

New Jersey Right To Know Components

	CAS-No.	Revision Date
Heptane	142-82-5	1993-02-16

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H400	Very toxic to aquatic life.
H410	Very toxic to aquatic life with long lasting effects.
Skin Irrit.	Skin irritation

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.12 Revision Date: 07/26/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.8
Revision Date 08/17/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Octane

Product Number : 296988
Brand : Sigma-Aldrich
Index-No. : 601-009-00-8

CAS-No. : 111-65-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 2), H225
Skin irritation (Category 2), H315
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H410	Very toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.

P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P312	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.
P331	Do NOT induce vomiting.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms	:	n-Octane
Formula	:	C_8H_{18}
Molecular weight	:	114.23 g/mol
CAS-No.	:	111-65-9
EC-No.	:	203-892-1
Index-No.	:	601-009-00-8

Hazardous components

Component	Classification	Concentration
n-octane		
	Flam. Liq. 2; Skin Irrit. 2; STOT SE 3; Asp. Tox. 1; Aquatic Acute 1; Aquatic Chronic 1; H225, H304, H315, H336, H410	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Dry powder Dry sand

Unsuitable extinguishing media
Do NOT use water jet.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with non-combustible absorbent material, (e.g. sand, earth, diatomaceous earth, vermiculite) and place in container for disposal according to local / national regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

hygroscopic
Storage class (TRGS 510): 3: Flammable liquids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
n-octane	111-65-9	TWA	75 ppm 350 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	385 ppm 1,800 mg/m3	USA. NIOSH Recommended Exposure Limits
	Remarks	15 minute ceiling value		
		TWA	500 ppm 2,350 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	300 ppm 1,450 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		STEL	375 ppm 1,800 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000
		PEL	300 ppm 1,450 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		STEL	375 ppm 1,800 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		TWA	300 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation		

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.2 mm
Break through time: 480 min
Material tested:Dermatril® P (KCL 743 / Aldrich Z677388, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: colourless
b)	Odour	characteristic
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -57 °C (-71 °F) - lit.
f)	Initial boiling point and boiling range	125 - 127 °C (257 - 261 °F) - lit.
g)	Flash point	13 °C (55 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 6.5 %(V) Lower explosion limit: 0.96 %(V)
k)	Vapour pressure	14.7 hPa (11.0 mmHg) at 20.0 °C (68.0 °F)
l)	Vapour density	No data available
m)	Relative density	0.703 g/cm3 at 25 °C (77 °F)
n)	Water solubility	ca.0.007 g/l at 20 °C (68 °F)
o)	Partition coefficient: n-octanol/water	log Pow: 5.15
p)	Auto-ignition temperature	220 °C (428 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong acids, Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LC50 Inhalation - Rat - 4 h - 118,000 mg/m3

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
May cause drowsiness or dizziness.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
The substance or mixture is known to cause human aspiration toxicity hazards or has to be regarded as if it causes a human aspiration toxicity hazard.

Additional Information
RTECS: RG8400000

burning sensation, Cough, wheezing, laryngitis, Shortness of breath, Headache, Nausea, Vomiting, Central nervous system depression, narcosis

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	mortality LC50 - Oryzias latipes - 0.42 mg/l - 96.0 h
Toxicity to daphnia and	Immobilization EC50 - Daphnia magna (Water flea) - 0.38 mg/l - 48 h

other aquatic invertebrates

Toxicity to algae	Growth inhibition NOEC - Pseudokirchneriella subcapitata (microalgae) - 5.8 mg/l - 72 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Very toxic to aquatic life with long lasting effects.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1262 Class: 3 Packing group: II
Proper shipping name: Octanes
Reportable Quantity (RQ): Marine pollutant:yes
Poison Inhalation Hazard: No

IMDG
UN number: 1262 Class: 3 Packing group: II EMS-No: F-E, S-E
Proper shipping name: OCTANES
Marine pollutant:yes Marine pollutant: yes

IATA
UN number: 1262 Class: 3 Packing group: II
Proper shipping name: Octanes

15. REGULATORY INFORMATION

SARA 302 Components
This material does not contain any components with a section 302 EHS TPQ.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Acute Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Octane	111-65-9	1993-02-16

Pennsylvania Right To Know Components

	CAS-No.	Revision Date

Octane	111-65-9	1993-02-16

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H400	Very toxic to aquatic life.
H410	Very toxic to aquatic life with long lasting effects.
Skin Irrit.	Skin irritation

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.8 Revision Date: 08/17/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.6
Revision Date 03/09/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Nonane

Product Number : 296821
Brand : Sigma-Aldrich

CAS-No. : 111-84-2

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 3), H226
Skin irritation (Category 2), H315
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H226	Flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H410	Very toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.

P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P312	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.
P331	Do NOT induce vomiting.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms	:	n-Nonane
Formula	:	C_9H_{20}
Molecular weight	:	128.26 g/mol
CAS-No.	:	111-84-2
EC-No.	:	203-913-4

Hazardous components

Component	Classification	Concentration
Nonane		
	Flam. Liq. 3; Skin Irrit. 2; STOT SE 3; Asp. Tox. 1; Aquatic Acute 1; Aquatic Chronic 1; H226, H304, H315, H336, H410	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Move out of dangerous area.Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

Moisture sensitive.
Storage class (TRGS 510): 3: Flammable liquids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Nonane	111-84-2	TWA	200 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment		
		TWA	200 ppm 1,050 mg/m3	USA. NIOSH Recommended Exposure Limits
		PEL	200 ppm 1,050 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.2 mm
Break through time: 30 min
Material tested:Dermatril® P (KCL 743 / Aldrich Z677388, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance Form: liquid

		Colour: clear, colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -53 °C (-63 °F) - lit.
f)	Initial boiling point and boiling range	151 °C (304 °F) - lit.
g)	Flash point	31.0 °C (87.8 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 2.9 %(V) Lower explosion limit: 0.87 %(V)
k)	Vapour pressure	5.69 hPa (4.27 mmHg) at 25 °C (77 °F)
l)	Vapour density	No data available
m)	Relative density	0.718 g/cm3 at 25 °C (77 °F)
n)	Water solubility	0.0002 g/l at 25 °C (77 °F) - slightly soluble
o)	Partition coefficient: n-octanol/water	log Pow: 5.65
p)	Auto-ignition temperature	205.0 °C (401.0 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	1.008 mm2/s at 20 °C (68 °F) -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Surface tension	22.38 mN/m at 25 °C (77 °F)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

LC50 Inhalation - Rat - male - 4 h - 23,760 mg/m3
(OECD Test Guideline 403)

Dermal: No data available

No data available

Skin corrosion/irritation
Skin - Rat
Result: Skin irritation
(Draize Test)

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
Ames test
S. typhimurium
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information

Repeated dose toxicity	Rat - female - Oral - NOAEL : 100 mg/kg - OECD Test Guideline 408

RTECS: RA6115000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

No data available

Toxicity to daphnia and other aquatic invertebrates	static test EC50 - Daphnia magna (Water flea) - 0.2 mg/l - 48 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Very toxic to aquatic life with long lasting effects.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Contact a licensed professional waste disposal service to dispose of this material. Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1920 Class: 3 Packing group: III
Proper shipping name: Nonanes
Reportable Quantity (RQ): Marine pollutant:yes
Poison Inhalation Hazard: No

IMDG
UN number: 1920 Class: 3 Packing group: III EMS-No: F-E, S-E
Proper shipping name: NONANES
Marine pollutant:yes Marine pollutant: yes

IATA
UN number: 1920 Class: 3 Packing group: III
Proper shipping name: Nonanes

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Acute Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Nonane	111-84-2	1993-02-16

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Nonane	111-84-2	1993-02-16

New Jersey Right To Know Components

	CAS-No.	Revision Date
Nonane	111-84-2	1993-02-16

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H226	Flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H400	Very toxic to aquatic life.
H410	Very toxic to aquatic life with long lasting effects.
Skin Irrit.	Skin irritation

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	
Flammability:	3
Physical Hazard	0

NFPA Rating

Health hazard:	2
Fire Hazard:	3
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.6 Revision Date: 03/09/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.10
Revision Date 03/22/2017
Print Date 10/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Decane

Product Number : 457116
Brand : Sigma-Aldrich

CAS-No. : 124-18-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 3), H226
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H226	Flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P280	Wear protective gloves/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.

P331	Do NOT induce vomiting.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS
No information available.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	$C_{10}H_{22}$
Molecular weight	:	142.28 g/mol
CAS-No.	:	124-18-5
EC-No.	:	204-686-4

Hazardous components

Component	Classification	Concentration
Decane		
	Flam. Liq. 3; Asp. Tox. 1; H226, H304	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Move out of dangerous area. Show this safety data sheet to the doctor in attendance. Symptoms of poisoning may appear several hours later. Do not leave the victim unattended.

If inhaled
If unconscious, place in recovery position and seek medical advice. If symptoms persist, call a physician.

In case of skin contact
If on skin, rinse well with water. If on clothes, remove clothes.

In case of eye contact
Flush eyes with water as a precaution. Remove contact lenses. Protect unharmed eye. Keep eye wide open while rinsing. If eye irritation persists, consult a specialist.

If swallowed
Keep respiratory tract clear. Do NOT induce vomiting. Do not give milk or alcoholic beverages. Never give anything by mouth to an unconscious person. If symptoms persist, call a physician. Take victim immediately to hospital.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Alcohol-resistant foam Carbon dioxide (CO2) Dry chemical

Unsuitable extinguishing media
High volume water jet

5.2 Special hazards arising from the substance or mixture
Do not allow run-off from fire fighting to enter drains or water courses.

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Collect contaminated fire extinguishing water separately. This must not be discharged into drains. Fire residues and contaminated fire extinguishing water must be disposed of in accordance with local regulations. For safety reasons in case of fire, cans should be stored separately in closed containments. Use a water spray to cool fully closed containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent product from entering drains. Prevent further leakage or spillage if safe to do so. If the product contaminates rivers and lakes or drains inform respective authorities.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with non-combustible absorbent material, (e.g. sand, earth, diatomaceous earth, vermiculite) and place in container for disposal according to local / national regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid formation of aerosol. Do not breathe vapours/dust. For personal protection see section 8. Smoking, eating and drinking should be prohibited in the application area. Take precautionary measures against static discharges. Provide sufficient air exchange and/or exhaust in work rooms. Open drum carefully as content may be under pressure. Dispose of rinse water in accordance with local and national regulations.
Do not spray on a naked flame or any incandescent material.Take necessary action to avoid static electricity discharge (which might cause ignition of organic vapours).Keep away from open flames, hot surfaces and sources of ignition.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
No smoking. Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage. Observe label precautions. Electrical installations / working materials must comply with the technological safety standards.

Store under inert gas. No decomposition if stored and applied as directed.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.
Hazardous components without workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
When using do not eat or drink. When using do not smoke. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Eye wash bottle with pure water Tightly fitting safety goggles

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

The suitability for a specific workplace should be discussed with the producers of the protective gloves.

Body Protection
Impervious clothing, Choose body protection according to the amount and concentration of the dangerous substance at the work place.

Control of environmental exposure
Prevent product from entering drains. Prevent further leakage or spillage if safe to do so. If the product contaminates rivers and lakes or drains inform respective authorities.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid, clear Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -30 °C (-22 °F) - lit.
f)	Initial boiling point and boiling range	174 °C (345 °F) - lit.
g)	Flash point	57.4 °C (135.3 °F) - Pensky-Martens closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 2.6 %(V) Lower explosion limit: 0.8 %(V)
k)	Vapour pressure	5.1 hPa (3.8 mmHg) at 37.7 °C (99.9 °F) 1.3 hPa (1.0 mmHg) at 16.5 °C (61.7 °F) 1 hPa (1 mmHg) at 20 °C (68 °F)
l)	Vapour density	No data available
m)	Relative density	0.73 g/cm3 at 25 °C (77 °F)
n)	Water solubility	No data available

o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	210.0 °C (410.0 °F) 206 °C (403 °F) at 1,013 hPa (760 mmHg)
q)	Decomposition temperature	No data available
r)	Viscosity	1.16 mm2/s at 20 °C (68 °F) -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No decomposition if stored and applied as directed.

10.2 Chemical stability
No decomposition if stored and applied as directed.
No decomposition if stored and applied as directed.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Carbon oxides
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male and female - > 5,000 mg/kg
(OECD Test Guideline 401)

LC50 Inhalation - Rat - male - 8 h - > 1369 ppm
(OECD Test Guideline 403)

LC50 Inhalation - Rat - male and female - 4 h - > 5.6 mg/l
(OECD Test Guideline 403)

LD50 Dermal - Rabbit - male and female - > 5,000 mg/kg
(OECD Test Guideline 402)

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation - 4 h
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
Maximisation Test - Guinea pig
Result: Does not cause skin sensitisation.
(OECD Test Guideline 406)

Germ cell mutagenicity
Ames test
S. typhimurium
Result: negative

Mutagenicity (micronucleus test)
Mouse - male and female
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information

Repeated dose toxicity: Rat - male and female - Oral - NOAEL : > 5,000 mg/kg

RTECS: HD6550000

Acts as a simple asphyxiant by displacing air., anesthetic effects, Difficulty in breathing, Headache, Dizziness, Prolonged or repeated exposure to skin causes defatting and dermatitis., narcosis

Solvents may degrease the skin.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	semi-static test LC50 - Oncorhynchus mykiss (rainbow trout) - > 1,000 mg/l - 96 h (OECD Test Guideline 203)
Toxicity to daphnia and other aquatic invertebrates	static test EC50 - Daphnia magna (Water flea) - > 1,000 mg/l - 48 h
Toxicity to algae	static test EC50 - Pseudokirchneriella subcapitata - > 1,000 mg/l - 72 h (OECD Test Guideline 201)

12.2 Persistence and degradability

Biodegradability	aerobic - Exposure time 28 d Result: 83.2 % - Readily biodegradable. (OECD Test Guideline 301F)

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Do not dispose of waste into sewer. Do not contaminate ponds, waterways or ditches with chemical or used container. Send to a licensed waste management company.

Contaminated packaging
Empty remaining contents. Dispose of as unused product. Do not re-use empty containers. Do not burn, or use a cutting torch on, the empty drum.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 2247 Class: 3 Packing group: III
Proper shipping name: n-Decane
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
UN number: 2247 Class: 3 Packing group: III EMS-No: F-E, S-E
Proper shipping name: n-DECANE

IATA
UN number: 2247 Class: 3 Packing group: III
Proper shipping name: n-Decane

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard, Chronic Health Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Decane	124-18-5	2007-03-01

	CAS-No.	Revision Date
Decane	124-18-5	2007-03-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Decane	124-18-5	2007-03-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H226	Flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	*
Flammability:	2
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	2
Reactivity Hazard:	0

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.10 Revision Date: 03/22/2017 Print Date: 10/19/2018

SAFETY DATA SHEET

Version 4.8
Revision Date 06/19/2015
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Undecane

Product Number : U407
Brand : Aldrich

CAS-No. : 1120-21-4

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 4), H227
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H227 Combustible liquid.
H304 May be fatal if swallowed and enters airways.

Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P280 Wear protective gloves/ eye protection/ face protection.
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER or doctor/ physician.
P331 Do NOT induce vomiting.
P370 + P378 In case of fire: Use dry sand, dry chemical or alcohol-resistant foam for extinction.
P403 + P235 Store in a well-ventilated place. Keep cool.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Repeated exposure may cause skin dryness or cracking.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms	:	Hendecane n-Undecane
Formula	:	$C_{11}H_{24}$
Molecular weight	:	156.31 g/mol
CAS-No.	:	1120-21-4
EC-No.	:	214-300-6

Hazardous components

Component	Classification	Concentration
Undecane		
	Flam. Liq. 4; Asp. Tox. 1; H227, H304	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

Carbon oxides

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up

Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal.

6.4 Reference to other sections

For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.
Storage class (TRGS 510): Flammable liquids

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.2 mm
Break through time: 58 min

Material tested:Dermatril® P (KCL 743 / Aldrich Z677388, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: clear Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -26 °C (-15 °F) - lit.
f)	Initial boiling point and boiling range	196 °C (385 °F) - lit.
g)	Flash point	62.0 °C (143.6 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	0.6 hPa (0.5 mmHg) at 25 °C (77 °F)
l)	Vapour density	No data available
m)	Relative density	0.74 g/cm3 at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	log Pow: 6.42 at 25 °C (77 °F)
p)	Auto-ignition temperature	202 °C (396 °F) at 101.3 hPa (76.0 mmHg)
q)	Decomposition temperature	No data available
r)	Viscosity	1.579 mm2/s at 20 °C (68 °F) -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Bases, Oxidizing agents, Reducing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male and female - 5,000 mg/kg
(OECD Test Guideline 401)

LC50 Inhalation - Rat - male and female - 4 h - > 6.1 mg/l

LD50 Dermal - Rabbit - male and female - > 5,000 mg/kg
(OECD Test Guideline 402)

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
Maximisation Test (GPMT) - Guinea pig
Result: Did not cause sensitisation on laboratory animals.
(OECD Test Guideline 406)

Germ cell mutagenicity
Chromosome aberration test in vitro
lymphocyte
Result: negative

Rat - male and female
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information

Repeated dose toxicity - Rat - male and female - Oral - No observed adverse effect level - > 5,000 mg/kg

Repeated dose toxicity - Rat - male and female - inhalation (vapour) - No observed adverse effect level - > 10.4 mg/kg
RTECS: YQ1525000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability

Biodegradability	aerobic - Exposure time 28 d Result: 77 % - Readily biodegradable (OECD Test Guideline 301)

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber. Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 2330 Class: 3 Packing group: III
Proper shipping name: Undecane
Reportable Quantity (RQ):

Poison Inhalation Hazard: No

IMDG
UN number: 2330 Class: 3 Packing group: III EMS-No: F-E, S-E
Proper shipping name: UNDECANE

IATA
UN number: 2330 Class: 3 Packing group: III
Proper shipping name: Undecane

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Undecane	1120-21-4	2007-03-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Undecane	1120-21-4	2007-03-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H227	Combustible liquid.
H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	
Flammability:	2
Physical Hazard	0

NFPA Rating

Health hazard:	2
Fire Hazard:	2
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling

or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.8 Revision Date: 06/19/2015 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.10
Revision Date 06/11/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Dodecane

Product Number : 297879
Brand : Sigma-Aldrich

CAS-No. : 112-40-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 4), H227
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H227 Combustible liquid.
H304 May be fatal if swallowed and enters airways.

Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P280 Wear protective gloves/ eye protection/ face protection.
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P331 Do NOT induce vomiting.
P370 + P378 In case of fire: Use dry sand, dry chemical or alcohol-resistant foam for extinction.
P403 + P235 Store in a well-ventilated place. Keep cool.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	$C_{12}H_{26}$
Molecular weight	:	170.33 g/mol
CAS-No.	:	112-40-3
EC-No.	:	203-967-9
Registration number	:	01-2119486573-28-XXXX

Hazardous components

Component	Classification	Concentration
Dodecane		
	Flam. Liq. 4; Asp. Tox. 1; H227, H304	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up

Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal.

6.4 Reference to other sections

For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

Handle and store under inert gas. hygroscopic
Storage class (TRGS 510): 10: Combustible liquids

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.2 mm
Break through time: 30 min

Material tested:Dermatril® P (KCL 743 / Aldrich Z677388, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid, clear Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -9.6 °C (14.7 °F)
f)	Initial boiling point and boiling range	215 - 217 °C (419 - 423 °F)
g)	Flash point	71 °C (160 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Lower explosion limit: 0.6 %(V)
k)	Vapour pressure	1 hPa (1 mmHg) at 47.80 °C (118.04 °F)
l)	Vapour density	5.88 - (Air = 1.0)
m)	Relative density	0.75 g/mL at 25 °C (77 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	log Pow: 6.98 at 25 °C (77 °F)
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density 5.88 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Exposure to moisture may affect product quality.
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LC50 Oral - Rat - > 5,000 mg/kg
(OECD Test Guideline 401)

LC50 Inhalation - Rat - 4 h - > 9.3 mg/l
(OECD Test Guideline 403)

LC50 Inhalation - Rat - 4 h - > 5.6 mg/l
(OECD Test Guideline 403)

LD50 Dermal - Rabbit - > 5,000 mg/kg
(OECD Test Guideline 402)
Remarks: No data available

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: slight irritation
Remarks: (RTECS)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Possible damages: slight irritation

Respiratory or skin sensitisation
Maximisation Test - Guinea pig
Did not cause sensitisation on laboratory animals.
(OECD Test Guideline 406)

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
The substance or mixture is known to cause human aspiration toxicity hazards or has to be regarded as if it causes a human aspiration toxicity hazard.Aspiration hazard, Aspiration may cause pulmonary oedema and pneumonitis.

Additional Information
RTECS: JR2125000

Cough, irritant effects, Dizziness, Headache, Shortness of breath
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated. It generally applies for aliphatic hydrocarbons with 6 - 18 carbon atoms that they may cause pneumonia, in some cases also pulmonary oedema, upon direct inhalation, i.e. in conditions that can occur only in very special circumstances (nebulizations, spraying, inhalation of aerosols and similar). After absorption of very large quantities: narcosis.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Oncorhynchus mykiss (rainbow trout) - > 1,000 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates	Remarks: No toxicity at the limit of solubility
Toxicity to algae	EC50 - Skeletonema costatum (marine diatom) - 57,100 mg/l - 72 h

12.2 Persistence and degradability

Biodegradability	aerobic - Exposure time 28 d Result: 83 % - Readily biodegradable. (OECD Test Guideline 301F)

12.3 Bioaccumulative potential

Bioaccumulation	Leuciscus idus melanotus - 3 d - 37 µg/l Bioconcentration factor (BCF): 52

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber. Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
NA-Number: 1993 Class: NONE Packing group: III
Proper shipping name: Combustible liquid, n.o.s. (Dodecane)
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Dodecane	112-40-3	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Dodecane	112-40-3	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H227	Combustible liquid.
H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	1
Chronic Health Hazard:	
Flammability:	2

Physical Hazard	0

NFPA Rating

Health hazard:	1
Fire Hazard:	2
Reactivity Hazard:	0

Further information

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.10 Revision Date: 06/11/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.8
Revision Date 08/15/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Tridecane

Product Number : T57401
Brand : Aldrich

CAS-No. : 629-50-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 4), H227
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H227	Combustible liquid.
H304	May be fatal if swallowed and enters airways.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P280	Wear protective gloves/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P331	Do NOT induce vomiting.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	$C_{13}H_{28}$
Molecular weight	:	184.36 g/mol
CAS-No.	:	629-50-5
EC-No.	:	211-093-4

Hazardous components

Component	Classification	Concentration
Tridecane		
	Flam. Liq. 4; Asp. Tox. 1; H227, H304	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Unsuitable extinguishing media
Do NOT use water jet.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up

Contain spillage, and then collect with non-combustible absorbent material, (e.g. sand, earth, diatomaceous earth, vermiculite) and place in container for disposal according to local / national regulations (see section 13). Keep in suitable, closed containers for disposal.

6.4 Reference to other sections

For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.
Hazardous components without workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 30 min

Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: clear, liquid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -6 - -4 °C (21 - 25 °F) - lit.
f)	Initial boiling point and boiling range	110 - 112 °C (230 - 234 °F) at 16 hPa (12 mmHg) - lit. 234 °C (453 °F) - lit.
g)	Flash point	79 °C (174 °F)
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	6.37 - (Air = 1.0)
m)	Relative density	0.756 g/cm3 at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	2.34 mm2/s at 20 °C (68 °F) -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density 6.37 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity

LD50 Oral - Rat - male and female - > 5,000 mg/kg
(OECD Test Guideline 401)

LC50 Inhalation - Rat - male and female - 4 h - > 4.951 mg/l
(OECD Test Guideline 403)

LD50 Dermal - Rat - male and female - > 2,000 mg/kg
(OECD Test Guideline 402)

LD50 Intravenous - Mouse - 1,161 mg/kg

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation - 4 h
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
Maximisation Test - Guinea pig
Result: Does not cause skin sensitisation.
(OECD Test Guideline 406)

Germ cell mutagenicity
S. typhimurium
Result: negative

Mutagenicity (micronucleus test)
Mouse - male and female
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information

Repeated dose toxicity	Rat - male and female - Oral - NOAEL : >= 1,000 mg/kg

RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

Toxicity to daphnia and other aquatic invertebrates	static test EC50 - Daphnia magna (Water flea) - > 0.002 mg/l - 48 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
NA-Number: 1993 Class: NONE Packing group: III
Proper shipping name: Combustible liquid, n.o.s. (Tridecane)
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG

Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Fire Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Tridecane	629-50-5	

	CAS-No.	Revision Date
Tridecane	629-50-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Tridecane	629-50-5	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H227	Combustible liquid.
H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	2
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	2
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.8 Revision Date: 08/15/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.10
Revision Date 06/01/2016
Print Date 11/09/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Tetradecane

Product Number : 172456
Brand : Aldrich

CAS-No. : 629-59-4

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H304 May be fatal if swallowed and enters airways.

Precautionary statement(s)
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P331 Do NOT induce vomiting.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{14}H_{30}$

Molecular weight	:	198.39 g/mol
CAS-No.	:	629-59-4
EC-No.	:	211-096-0

Hazardous components

Component	Classification	Concentration
Tetradecane		
	Asp. Tox. 1; H304	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.
Hazardous components without workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 60 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: clear, liquid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 5.5 °C (41.9 °F) - lit.
f)	Initial boiling point and boiling range	252 - 254 °C (486 - 489 °F) - lit.
g)	Flash point	100 °C (212 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 6.5 %(V) Lower explosion limit: 0.5 %(V)
k)	Vapour pressure	1 hPa (1 mmHg) at 76.4 °C (169.5 °F) < 133 hPa (< 100 mmHg) at 178.3 °C (352.9 °F)
l)	Vapour density	6.85 - (Air = 1.0)
m)	Relative density	0.762 g/cm3 at 20 °C (68 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	log Pow: 7.2
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	2.81 mm2/s at 20 °C (68 °F) -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	6.85 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - > 15,000 mg/kg
(OECD Test Guideline 401)

LD50 Dermal - Rabbit - > 5,000 mg/kg
(OECD Test Guideline 402)

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
- Guinea pig
Result: Did not cause sensitisation on laboratory animals.
(OECD Test Guideline 406)

Germ cell mutagenicity
No data available

Carcinogenicity

Carcinogenicity - Mouse - Skin
Tumorigenic:Equivocal tumorigenic agent by RTECS criteria. Tumorigenic:Tumors at site or application.

Carcinogenicity - Mouse - Skin
Tumorigenic:Equivocal tumorigenic agent by RTECS criteria. Skin and Appendages: Other: Tumors. Tumorigenic:Tumors at site or application.

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
The substance or mixture is known to cause human aspiration toxicity hazards or has to be regarded as if it causes a human aspiration toxicity hazard.

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	- Oncorhynchus mykiss (rainbow trout) - 1,000 mg/l - 96 h (OECD Test Guideline 203)
Toxicity to daphnia and other aquatic invertebrates	- Daphnia magna (Water flea) - > 1,000 mg/l - 48 h
Toxicity to algae	- Skeletonema costatum (marine diatom) - > 1,000 mg/l - 72 h (ISO 10253)

12.2 Persistence and degradability
Biodegradability Result: - Readily biodegradable

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Tetradecane	629-59-4	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Tetradecane	629-59-4	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	1
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	1
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.10 Revision Date: 06/01/2016 Print Date: 11/09/2018

SAFETY DATA SHEET

Version 4.5
Revision Date 06/26/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Pentadecane

Product Number : P3406
Brand : Aldrich

CAS-No. : 629-62-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H304 May be fatal if swallowed and enters airways.

Precautionary statement(s)
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER or doctor/ physician.
P331 Do NOT induce vomiting.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Repeated exposure may cause skin dryness or cracking.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	$C_{15}H_{32}$
Molecular Weight	:	212.41 g/mol
CAS-No.	:	629-62-9
EC-No.	:	211-098-1

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.
For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 30 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid, clear Colour: colourless
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 8 - 10 °C (46 - 50 °F) - lit.
f)	Initial boiling point and boiling range	270 °C (518 °F) - lit.
g)	Flash point	132.00 °C (269.60 °F) - closed cup
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	< 0.2 hPa (< 0.2 mmHg) at 20 °C (68 °F)
l)	Vapour density	no data available
m)	Relative density	0.769 g/mL at 25 °C (77 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	< 7 mm2/s at 40 °C (104 °F) -
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products

Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - rat - > 5,000 mg/kg
(OECD Test Guideline 401)

LC50 Inhalation - rat - 4 h - > 5.8 mg/l
(OECD Test Guideline 403)

LD50 Dermal - rabbit - > 3,160 mg/kg
(OECD Test Guideline 402)
Remarks: no data available

no data available

Skin corrosion/irritation
Skin - rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information
RTECS: RZ1800000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - other fish - > 1,000 mg/l (OECD Test Guideline 203)
Toxicity to algae	EC50 - Skeletonema costatum - > 10,000 mg/l - 72 h (ISO 10253)

12.2 Persistence and degradability

Biodegradability	Result: - Readily biodegradable. (OECD Test Guideline 306)

12.3 Bioaccumulative potential

no data available

12.4 Mobility in soil

no data available

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Pentadecane	629-62-9	

New Jersey Right To Know Components

	CAS-No.	Revision Date

Pentadecane	629-62-9

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.5 Revision Date: 06/26/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.6
Revision Date 05/07/2015
Print Date 10/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Hexadecane

Product Number : 296317
Brand : Sigma-Aldrich

CAS-No. : 544-76-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H304 May be fatal if swallowed and enters airways.

Precautionary statement(s)
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER or doctor/ physician.
P331 Do NOT induce vomiting.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Repeated exposure may cause skin dryness or cracking.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	$C_{16}H_{34}$
Molecular weight	:	226.44 g/mol
CAS-No.	:	544-76-3
EC-No.	:	208-878-9

Hazardous components

Component	Classification	Concentration
Hexadecane		
	Asp. Tox. 1; H304	<= 100 %

No components need to be disclosed according to the applicable regulations.
For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.
Storage class (TRGS 510): Combustible liquids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 60 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls.

If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: colourless
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 18 °C (64 °F)
f)	Initial boiling point and boiling range	285 °C (545 °F) at 1,013 hPa (760 mmHg)
g)	Flash point	135 °C (275 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	0.004 hPa (0.003 mmHg) at 20 °C (68 °F) 1 hPa (1 mmHg) at 105.3 °C (221.5 °F)
l)	Vapour density	7.82 - (Air = 1.0)
m)	Relative density	0.773 g/cm3
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	log Pow: 8.2 at 25 °C (77 °F)
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	4.29 mm2/s at 20 °C (68 °F) -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	7.82 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - > 5,000 mg/kg
(OECD Test Guideline 401)

Inhalation: No data available

LD50 Dermal - Rabbit - > 3,160 mg/kg
(OECD Test Guideline 402)

TDLo Intraperitoneal - Mouse - 1,546 mg/kg
Remarks: Liver:Changes in liver weight.

LDLO Intravenous - Mouse - 9,821 mg/kg
Remarks: Behavioral:Altered sleep time (including change in righting reflex).

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)
Remarks: Repeated or prolonged contact with the mixture may cause removal of natural fat from the skin resulting in desiccation of the skin.

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information
RTECS: ML9200000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Fish - > 1,028 mg/l - 96 h

12.2 Persistence and degradability

Biodegradability	Result: - Readily biodegradable

12.3 Bioaccumulative potential

Bioaccumulation	Salmo salar (Atlantic salmon) - 7 d - 1,700 µg/l
	Bioconcentration factor (BCF): 5.6

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Hexadecane	544-76-3	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Hexadecane	544-76-3	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.6 Revision Date: 05/07/2015 Print Date: 10/19/2018

SAFETY DATA SHEET

Version 5.5
Revision Date 12/28/2017
Print Date 11/09/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Heptadecane

Product Number : 128503
Brand : Aldrich

CAS-No. : 629-78-7

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H304 May be fatal if swallowed and enters airways.

Precautionary statement(s)
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P331 Do NOT induce vomiting.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{17}H_{36}$
Molecular weight : 240.47 g/mol

CAS-No. : 629-78-7
EC-No. : 211-108-4

Hazardous components

Component	Classification	Concentration
N-Heptadecane		
	Asp. Tox. 1; H304	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.
Storage class (TRGS 510): 10: Combustible liquids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 30 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 20 - 22 °C (68 - 72 °F) - lit.
f)	Initial boiling point and boiling range	302 °C (576 °F) - lit.
g)	Flash point	149 °C (300 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	1 hPa (1 mmHg) at 115 °C (239 °F)
l)	Vapour density	8.3 - (Air = 1.0)
m)	Relative density	0.777 g/mL at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Relative vapour density	8.3 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products

Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data availableThe substance or mixture is known to cause human aspiration toxicity hazards or has to be regarded as if it causes a human aspiration toxicity hazard.

Additional Information
RTECS: MI3550000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

No data available

12.2 Persistence and degradability

No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
N-Heptadecane	629-78-7	

New Jersey Right To Know Components

	CAS-No.	Revision Date
N-Heptadecane	629-78-7	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
H304	May be fatal if swallowed and enters airways.

HMIS Rating
Health hazard: 0

Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.5 Revision Date: 12/28/2017 Print Date: 11/09/2018

SAFETY DATA SHEET

Version 5.4
Revision Date 04/08/2016
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Octadecane

Product Number : O652
Brand : Aldrich

CAS-No. : 593-45-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Aspiration hazard (Category 1), H304

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H304 May be fatal if swallowed and enters airways.

Precautionary statement(s)
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P331 Do NOT induce vomiting.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{18}H_{38}$

Molecular weight	:	254.49 g/mol
CAS-No.	:	593-45-3
EC-No.	:	209-790-3

Hazardous components

Component	Classification	Concentration
Octadecane		
	Asp. Tox. 1; H304	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.
Hazardous components without workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 60 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 26 - 29 °C (79 - 84 °F) - lit.
f)	Initial boiling point and boiling range	317 °C (603 °F) - lit.
g)	Flash point	166 °C (331 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	1 hPa (1 mmHg) at 119 °C (246 °F)
l)	Vapour density	No data available
m)	Relative density	0.777 g/mL at 25 °C (77 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	log Pow: 10.37 at 25 °C (77 °F)
p)	Auto-ignition temperature	235 °C (455 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	4.03 mm2/s -
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products

Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male and female - > 5,000 mg/kg
(OECD Test Guideline 401)

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
Information given is based on data obtained from similar substances.

Germ cell mutagenicity
Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - other fish - > 1,028 mg/l - 96 h (OECD Test Guideline 203) Remarks: No data available
Toxicity to daphnia and other aquatic	EC50 - other microorganisms - > 3,000 mg/l - 48 h (ISO 14669 and PARCOM method)

invertebrates

Toxicity to algae	EC50 - Skeletonema costatum (marine diatom) - > 10,000 mg/l - 72 h (ISO 10253)

12.2 Persistence and degradability

Biodegradability	Result: 74 % - Readily biodegradable (OECD Test Guideline 306)

12.3 Bioaccumulative potential

No data available

12.4 Mobility in soil

No data available

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product

Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging

Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)

Not dangerous goods

IMDG

Not dangerous goods

IATA

Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components

No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components

This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards

No SARA Hazards

Massachusetts Right To Know Components

No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Octadecane	593-45-3	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Octadecane	593-45-3	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Asp. Tox.	Aspiration hazard
H304	May be fatal if swallowed and enters airways.

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.4 Revision Date: 04/08/2016 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.3
Revision Date 07/01/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Nonadecane

Product Number : N28906
Brand : Aldrich

CAS-No. : 629-92-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{19}H_{40}$
Molecular Weight : 268.52 g/mol
CAS-No. : 629-92-5

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Solidified mass or fragments Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 30 - 34 °C (86 - 93 °F) - lit.
f)	Initial boiling point and boiling range	330 °C (626 °F) - lit.
g)	Flash point	100 °C (212 °F) - closed cup
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	0.786 g/mL at 25 °C (77 °F)

n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: 211-116-8

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Nonadecane	629-92-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Nonadecane	629-92-5	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.3 Revision Date: 07/01/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.3
Revision Date 03/03/2016
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Eicosane

Product Number : 219274
Brand : Aldrich

CAS-No. : 112-95-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{20}H_{42}$
Molecular weight : 282.55 g/mol
CAS-No. : 112-95-8
EC-No. : 204-018-1

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 35 - 37 °C (95 - 99 °F) - lit.
f)	Initial boiling point and boiling range	220 °C (428 °F) at 40 hPa (30 mmHg) - lit.
g)	Flash point	> 113.00 °C (> 235.40 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	No data available

	explosive limits	
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	No data available
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Bulk density	789 kg/m3

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)

Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Icosane	112-95-8	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Icosane	112-95-8	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.3 Revision Date: 03/03/2016 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.2
Revision Date 06/30/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Heneicosane

Product Number : 286052
Brand : Aldrich

CAS-No. : 629-94-7

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{21}H_{44}$
Molecular Weight : 296.57 g/mol
CAS-No. : 629-94-7

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 39 - 41 °C (102 - 106 °F) - lit.
f)	Initial boiling point and boiling range	356.1 °C (673.0 °F) at 1,013 hPa (760 mmHg) 100 °C (212 °F) at 3 hPa (2 mmHg) - lit.
g)	Flash point	113 °C (235 °F) - closed cup
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	< 1 hPa (< 1 mmHg) at 20 °C (68 °F)
l)	Vapour density	no data available
m)	Relative density	no data available
n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: 211-118-9

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Henicosane	629-94-7	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Henicosane	629-94-7	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.2 Revision Date: 06/30/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.6
Revision Date 09/13/2016
Print Date 11/09/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Docosane

Product Number : 134457
Brand : Aldrich

CAS-No. : 629-97-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{22}H_{46}$
Molecular weight : 310.60 g/mol
CAS-No. : 629-97-0
EC-No. : 211-121-5

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: crystalline Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 42 - 45 °C (108 - 113 °F) - lit.
f)	Initial boiling point and boiling range	369 °C (696 °F) - lit.
g)	Flash point	113 °C (235 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	No data available

	explosive limits	
k)	Vapour pressure	< 1 hPa (< 1 mmHg) at 21.1 °C (70.0 °F)
l)	Vapour density	No data available
m)	Relative density	0.778 g/cm3 at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	mortality NOEC - Cyprinodon variegatus (sheepshead minnow) - 500 mg/l - 96 h
	LC50 - Cyprinodon variegatus (sheepshead minnow) - > 500 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates	LC50 - Daphnia magna (Water flea) - > 530 mg/l - 48 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Docosane	629-97-0	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Docosane	629-97-0	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.6 Revision Date: 09/13/2016 Print Date: 11/09/2018

SAFETY DATA SHEET

Version 5.2
Revision Date 06/30/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Tricosane

Product Number : 263850
Brand : Aldrich

CAS-No. : 638-67-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{23}H_{48}$
Molecular Weight : 324.63 g/mol
CAS-No. : 638-67-5

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 46 - 47 °C (115 - 117 °F) - lit.
f)	Initial boiling point and boiling range	199 - 200 °C (390 - 392 °F) at 4 hPa (3 mmHg) - lit.
g)	Flash point	113 °C (235 °F) - closed cup
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	no data available

n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: 211-347-4

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA

Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Tricosane	638-67-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Tricosane	638-67-5	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.2 Revision Date: 06/30/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.3
Revision Date 06/25/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Tetracosane

Product Number : T8752
Brand : Aldrich

CAS-No. : 646-31-1

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{24}H_{50}$
Molecular Weight : 338.65 g/mol
CAS-No. : 646-31-1
EC-No. : 211-474-5

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 49 - 52 °C (120 - 126 °F) - lit.
f)	Initial boiling point and boiling range	391 °C (736 °F) - lit.
g)	Flash point	> 113.00 °C (> 235.40 °F) - closed cup
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or	no data available

	explosive limits	
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	no data available
n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: Not available

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Tetracosane	646-31-1	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Tetracosane	646-31-1	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.3 Revision Date: 06/25/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.2
Revision Date 07/01/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Pentacosane

Product Number : 286931
Brand : Aldrich

CAS-No. : 629-99-2

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{25}H_{52}$
Molecular Weight : 352.68 g/mol
CAS-No. : 629-99-2

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 30 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 53 - 56 °C (127 - 133 °F) - lit.
f)	Initial boiling point and boiling range	169 - 170 °C (336 - 338 °F) at 0.07 hPa (0.05 mmHg) - lit.
g)	Flash point	120 °C (248 °F) - closed cup
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	no data available

n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: 211-123-6

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA

Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Pentacosane	629-99-2	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Pentacosane	629-99-2	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.2 Revision Date: 07/01/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 5.3
Revision Date 06/30/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Hexacosane

Product Number : 241687
Brand : Aldrich

CAS-No. : 630-01-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{26}H_{54}$
Molecular Weight : 366.71 g/mol
CAS-No. : 630-01-3

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 55 - 58 °C (131 - 136 °F) - lit.
f)	Initial boiling point and boiling range	no data available
g)	Flash point	no data available
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	no data available

n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information

Bulk density	0.8032 kg/m3

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: 211-124-1

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Hexacosane	630-01-3	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Hexacosane	630-01-3	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.3 Revision Date: 06/30/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.5
Revision Date 11/09/2014
Print Date 04/05/2019

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Heptacosane

Product Number : 51560
Brand : Aldrich

CAS-No. : 593-49-7

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{27}H_{56}$
Molecular weight : 380.73 g/mol
CAS-No. : 593-49-7

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: flakes Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 58 - 60 °C (136 - 140 °F) - lit.
f)	Initial boiling point and boiling range	270 °C (518 °F) at 20 hPa (15 mmHg) - lit.
g)	Flash point	120 °C (248 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or	No data available

	explosive limits	
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	No data available
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: 209-792-4

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Heptacosane	593-49-7	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Heptacosane	593-49-7	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	1
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.5 Revision Date: 11/09/2014 Print Date: 04/05/2019

SAFETY DATA SHEET

Version 3.5
Revision Date 06/25/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Octacosane

Product Number : O504
Brand : Aldrich

CAS-No. : 630-02-4

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{28}H_{58}$
Molecular Weight : 394.76 g/mol
CAS-No. : 630-02-4
EC-No. : 211-125-7

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 57 - 62 °C (135 - 144 °F) - lit.
f)	Initial boiling point and boiling range	278 °C (532 °F) at 20 hPa (15 mmHg) - lit.
g)	Flash point	no data available
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or	no data available

	explosive limits	
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	no data available
n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG

Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Octacosane	630-02-4	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Octacosane	630-02-4	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.5 Revision Date: 06/25/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.4
Revision Date 06/25/2014
Print Date 10/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Nonacosane

Product Number : 284246
Brand : Aldrich

CAS-No. : 630-03-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{29}H_{60}$
Molecular Weight : 408.79 g/mol
CAS-No. : 630-03-5
EC-No. : 211-126-2

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: flakes Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 63 - 66 °C (145 - 151 °F)
f)	Initial boiling point and boiling range	286 °C (547 °F) at 20 hPa (15 mmHg)
g)	Flash point	no data available
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	no data available
n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available

t) Oxidizing properties no data available

9.2 Other safety information
no data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Nonacosane	630-03-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Nonacosane	630-03-5	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.4 Revision Date: 06/25/2014 Print Date: 10/19/2018

SAFETY DATA SHEET

Version 4.3
Revision Date 07/01/2014
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Triacontane

Product Number : 263842
Brand : Aldrich

CAS-No. : 638-68-6

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $C_{30}H_{62}$
Molecular Weight : 422.81 g/mol
CAS-No. : 638-68-6

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
no data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.Normal measures for preventive fire protection.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: flakes Colour: white
b)	Odour	no data available
c)	Odour Threshold	no data available
d)	pH	no data available
e)	Melting point/freezing point	Melting point/range: 64 - 67 °C (147 - 153 °F) - lit.
f)	Initial boiling point and boiling range	258 - 259 °C (496 - 498 °F) at 4 hPa (3 mmHg) - lit.
g)	Flash point	no data available
h)	Evapouration rate	no data available
i)	Flammability (solid, gas)	no data available
j)	Upper/lower flammability or explosive limits	no data available
k)	Vapour pressure	no data available
l)	Vapour density	no data available
m)	Relative density	no data available

n)	Water solubility	no data available
o)	Partition coefficient: n-octanol/water	no data available
p)	Auto-ignition temperature	no data available
q)	Decomposition temperature	no data available
r)	Viscosity	no data available
s)	Explosive properties	no data available
t)	Oxidizing properties	no data available

9.2 Other safety information

Bulk density	0.775 kg/m3

10. STABILITY AND REACTIVITY

10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agentsStrong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
no data available

Inhalation: no data available

Dermal: no data available

no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
no data available

no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: 211-349-5

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA

Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Triacontane	638-68-6	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Triacontane	638-68-6	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.3 Revision Date: 07/01/2014 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.8
Revision Date 05/27/2016
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Nitrogen

Product Number : 295574
Brand : Aldrich

CAS-No. : 7727-37-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Gases under pressure (Compressed gas), H280
Simple Asphyxiant,

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Warning

Hazard statement(s)
H280 Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statement(s)
P410 + P403 Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : N_2
Molecular weight : 28.01 g/mol

CAS-No. : 7727-37-9
EC-No. : 231-783-9

Hazardous components

Component	Classification	Concentration
Nitrogen		
	Press. Gas Compr. Gas; SA ; H280,	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Clean up promptly by sweeping or vacuum.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.
Storage class (TRGS 510): Gases

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

	Remarks	Asphyxia Adopted values or notations enclosed are those for which changes are proposed in the NIC See Notice of Intended Changes (NIC) Simple asphyxiant; see discussion covering Minimal Oxygen Content found in the 'Definitions and Notations' section following the NIC tables
		See Appendix F: Minimal Oxygen Content Asphyxia Simple asphyxiant; see discussion covering Minimal Oxygen Content found in the 'Definitions and Notations' section following the NIC tables

Hazardous components without workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash contact
Material: Chloroprene
Minimum layer thickness: 0.6 mm
Break through time: 30 min
Material tested:Camapren® (KCL 722 / Aldrich Z677493, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374

If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Compressed gas Colour: colourless
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -210 °C (-346 °F) - lit.
f)	Initial boiling point and boiling range	-196 °C (-321 °F) - lit.
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	0.97 g/cm3
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Nitrogen oxides (NOx)
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: QW9700000

May be harmful., Nausea, Headache, Vomiting, Acts as a simple asphyxiant by displacing air.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1066 Class: 2.2
Proper shipping name: Nitrogen, compressed
Reportable Quantity (RQ):

Poison Inhalation Hazard: No

IMDG
UN number: 1066 Class: 2.2 EMS-No: F-C, S-V
Proper shipping name: NITROGEN, COMPRESSED

IATA
UN number: 1066 Class: 2.2
Proper shipping name: Nitrogen, compressed

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Sudden Release of Pressure Hazard, Acute Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Nitrogen	7727-37-9	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date

Nitrogen	7727-37-9	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Nitrogen	7727-37-9	1993-04-24

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

	May displace oxygen and cause rapid suffocation.
H280	Contains gas under pressure; may explode if heated.
Press. Gas	Gases under pressure
SA	Simple Asphyxiant

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	1

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0
Special hazard.I:	SA

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.8 Revision Date: 05/27/2016 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.9
Revision Date 11/18/2014
Print Date 04/16/2019

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Oxygen

Product Number : 00476
Brand : Sigma-Aldrich
Index-No. : 008-001-00-8

CAS-No. : 7782-44-7

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Oxidising gases (Category 1), H270
Gases under pressure (Compressed gas), H280

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H270 May cause or intensify fire; oxidiser.
H280 Contains gas under pressure; may explode if heated.

Precautionary statement(s)
P220 Keep/Store away from clothing/ combustible materials.
P244 Keep reduction valves free from grease and oil.
P370 + P376 In case of fire: Stop leak if safe to do so.
P410 + P403 Protect from sunlight. Store in a well-ventilated place.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	O_2
Molecular weight	:	32.00 g/mol
CAS-No.	:	7782-44-7
Index-No.	:	008-001-00-8

Hazardous components

Component	Classification	Concentration
Oxygen		
	Ox. Gas 1; Press. Gas Compr. Gas; H270, H280	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Not applicable

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Not applicable

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Nature of decomposition products not known.

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Keep away from sources of ignition - No smoking.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place.

Contents under pressure.
Storage class (TRGS 510): Aerosols

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested:Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash contact
Material: Chloroprene
Minimum layer thickness: 0.6 mm
Break through time: 30 min
Material tested:Camapren® (KCL 722 / Aldrich Z677493, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators

and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: Compressed gas Colour: colourless
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -217.99 °C (-360.38 °F)
f)	Initial boiling point and boiling range	-182.99 °C (-297.38 °F) at 1,013 hPa (760 mmHg)
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	1.1 - (Air = 1.0)1.1 - (Air = 1.0)
m)	Relative density	No data available
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	The substance or mixture is classified as oxidizing with the category 1.

9.2 Other safety information

Relative vapour density	1.1 - (Air = 1.0) 1.1 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Phosphorus, Organic materials, Powdered metals

10.6 Hazardous decomposition products
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: RS2060000

Nausea, Dizziness, Unconsciousness, May be harmful.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1072 Class: 2.2 (5.1)
Proper shipping name: Oxygen, compressed
Reportable Quantity (RQ):

Poison Inhalation Hazard: No

IMDG
UN number: 1072 Class: 2.2 (5.1) EMS-No: F-C, S-W
Proper shipping name: OXYGEN, COMPRESSED

IATA
UN number: 1072 Class: 2.2 (5.1)
Proper shipping name: Oxygen, compressed

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Oxygen	7782-44-7	2007-03-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Oxygen	7782-44-7	2007-03-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Oxygen	7782-44-7	2007-03-01

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

H270	May cause or intensify fire; oxidiser.
H280	Contains gas under pressure; may explode if heated.
Ox. Gas	Oxidising gases
Press. Gas	Gases under pressure

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	1
Physical Hazard	3

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.9 Revision Date: 11/18/2014 Print Date: 04/16/2019

SAFETY DATA SHEET

Version 5.13
Revision Date 07/28/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Potassium hydroxide

Product Number : P5958
Brand : Sigma-Aldrich
Index-No. : 019-002-00-8

CAS-No. : 1310-58-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Corrosive to metals (Category 1), H290
Acute toxicity, Oral (Category 4), H302
Skin corrosion (Category 1A), H314
Serious eye damage (Category 1), H318
Acute aquatic toxicity (Category 3), H402

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H290 May be corrosive to metals.
H302 Harmful if swallowed.
H314 Causes severe skin burns and eye damage.
H402 Harmful to aquatic life.

Precautionary statement(s)
P234 Keep only in original container.
P260 Do not breathe dust or mist.
P264 Wash skin thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.

P273	Avoid release to the environment.
P280	Wear protective gloves/ protective clothing/ eye protection/ face protection.
P301 + P312 + P330	IF SWALLOWED: Call a POISON CENTER/doctor if you feel unwell. Rinse mouth.
P301 + P330 + P331	IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P310	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Immediately call a POISON CENTER/doctor.
P305 + P351 + P338 + P310	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.
P363	Wash contaminated clothing before reuse.
P390	Absorb spillage to prevent material damage.
P405	Store locked up.
P406	Store in corrosive resistant stainless steel container with a resistant inliner.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms	:	Caustic potash
Formula	:	HKO
Molecular weight	:	56.11 g/mol
CAS-No.	:	1310-58-3
EC-No.	:	215-181-3
Index-No.	:	019-002-00-8
Registration number	:	01-2119487136-33-XXXX

Hazardous components

Component	Classification	Concentration
caustic potash		
	Met. Corr. 1; Acute Tox. 4; Skin Corr. 1A; Eye Dam. 1; Aquatic Acute 3; H290, H302, H314, H402	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Take off contaminated clothing and shoes immediately. Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.Continue rinsing eyes during transport to hospital.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Gives off hydrogen by reaction with metals.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Absorbs carbon dioxide (CO_2) from air.

Air sensitive. strongly hygroscopic
Storage class (TRGS 510): 8B: Non-combustible, corrosive hazardous materials

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
caustic potash	1310-58-3	C	2 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract irritation Eye irritation Skin irritation		
		C	2 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	2 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

Derived No Effect Level (DNEL)

Application Area	Exposure routes	Health effect	Value
Workers	Inhalation	Long-term local effects	1 mg/m3
Consumers	Inhalation	Long-term local effects	1 mg/m3

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	13.5
e)	Melting point/freezing point	Melting point/range: 361 °C (682 °F) - lit.
f)	Initial boiling point and boiling range	1,320 °C (2,408 °F)
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	1 hPa (1 mmHg) at 719 °C (1,326 °F) 1 hPa (1 mmHg) at 714 °C (1,317 °F)
l)	Vapour density	No data available
m)	Relative density	2.044 g/cm3
n)	Water solubility	1,120 g/l - soluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Bulk density	1,300 kg/m3

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Heat of solution is very high, and with limited amounts of water, violent boiling may occur
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Do not heat above melting point.

10.5 Incompatible materials

Nitro compounds, Organic materials, Magnesium, Copper, Water, reacts violently with:, Metals, Light metals, Contact with aluminum, tin and zinc liberates hydrogen gas. Contact with n formation of shock-sensitive salts., vigorous reaction with:, Alkali metals, Halogens, Azides, Anhydrides

10.6 Hazardous decomposition products

Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Potassium oxides
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity

LD50 Oral - Rat - 333 mg/kg

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation

Skin - Rabbit
Result: Severe skin irritation - 24 h

Serious eye damage/eye irritation

Eyes - Rabbit
Result: Corrosive to eyes
(OECD Test Guideline 405)

Respiratory or skin sensitisation

No data available

Germ cell mutagenicity

No data available

In vitro mammalian cell gene mutation test
mouse lymphoma cells
Result: negative

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity

No data available

No data available

Specific target organ toxicity - single exposure

No data available

Specific target organ toxicity - repeated exposure

No data available

Aspiration hazard

No data available

Additional Information

RTECS: TT2100000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Gambusia affinis (Mosquito fish) - 80 mg/l - 96 h

12.2 Persistence and degradability
The methods for determining the biological degradability are not applicable to inorganic substances.

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Harmful to aquatic life.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1813 Class: 8 Packing group: II
Proper shipping name: Potassium hydroxide, solid
Reportable Quantity (RQ): 1000 lbs
Poison Inhalation Hazard: No

IMDG
UN number: 1813 Class: 8 Packing group: II EMS-No: F-A, S-B
Proper shipping name: POTASSIUM HYDROXIDE, SOLID

IATA
UN number: 1813 Class: 8 Packing group: II
Proper shipping name: Potassium hydroxide, solid

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Potassium hydroxide	1310-58-3	1989-08-11

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Potassium hydroxide	1310-58-3	1989-08-11

New Jersey Right To Know Components

	CAS-No.	Revision Date
Potassium hydroxide	1310-58-3	1989-08-11

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Acute Tox.	Acute toxicity
Aquatic Acute	Acute aquatic toxicity
Eye Dam.	Serious eye damage
H290	May be corrosive to metals.
H302	Harmful if swallowed.
H314	Causes severe skin burns and eye damage.
H318	Causes serious eye damage.
H402	Harmful to aquatic life.

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.13 Revision Date: 07/28/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.8
Revision Date 07/28/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Potassium carbonate

Product Number : P5833
Brand : Sigma-Aldrich

CAS-No. : 584-08-7

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Eye irritation (Category 2A), H319
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Warning

Hazard statement(s)
H315 Causes skin irritation.
H319 Causes serious eye irritation.
H335 May cause respiratory irritation.

Precautionary statement(s)
P261 Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264 Wash skin thoroughly after handling.
P271 Use only outdoors or in a well-ventilated area.
P280 Wear protective gloves/ eye protection/ face protection.
P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P304 + P340 + P312 IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.
P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove

	contact lenses, if present and easy to do. Continue rinsing.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P337 + P313	If eye irritation persists: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	CK_2O_3
Molecular weight	:	138.21 g/mol
CAS-No.	:	584-08-7
EC-No.	:	209-529-3
Registration number	:	01-2119532646-36-XXXX

Hazardous components

Component	Classification	Concentration
Potassium carbonate		
	Skin Irrit. 2; Eye Irrit. 2A; STOT SE 3; H315, H319, H335	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Storage class (TRGS 510): 13: Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.
Hazardous components without workplace control parameters

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber

Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particle respirator.For higher level protection use type OV/AG/P99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: crystalline Colour: white
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	11.0 - 13 at 138 g/l at 25 °C (77 °F)
e)	Melting point/freezing point	Melting point/range: 891 °C (1,636 °F) - lit.
f)	Initial boiling point and boiling range	No data available
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	2.428 g/cm3
n)	Water solubility	138 g/l at 20 °C (68 °F) - completely soluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Exposure to moisture

10.5 Incompatible materials
Acids, Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Carbon oxides, Potassium oxides
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male and female - > 2,000 mg/kg
(OECD Test Guideline 401)

Skin corrosion/irritation
Skin - Rabbit
Result: Irritations
Remarks: (IUCLID)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Eye irritation
Remarks: (IUCLID)

Respiratory or skin sensitisation
Germ cell mutagenicity
Ames test
Salmonella typhimurium
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity

Specific target organ toxicity - single exposure
May cause respiratory irritation. - Respiratory system

Specific target organ toxicity - repeated exposure

Aspiration hazard

Additional Information
RTECS: TS7750000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

12.2 Persistence and degradability
The methods for determining the biological degradability are not applicable to inorganic substances.

12.3 Bioaccumulative potential

12.4 Mobility in soil

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Potassium carbonate	584-08-7	

	CAS-No.	Revision Date
Potassium carbonate	584-08-7	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Potassium carbonate	584-08-7	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Eye Irrit.	Eye irritation
H315	Causes skin irritation.
H319	Causes serious eye irritation.
H335	May cause respiratory irritation.
Skin Irrit.	Skin irritation
STOT SE	Specific target organ toxicity - single exposure

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.8 Revision Date: 07/28/2018 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.10
Revision Date 10/03/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Calcium hydroxide

Product Number : 31219
Brand : Sigma-Aldrich

CAS-No. : 1305-62-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Serious eye damage (Category 1), H318
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335
Acute aquatic toxicity (Category 3), H402

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H315 Causes skin irritation.
H318 Causes serious eye damage.
H335 May cause respiratory irritation.
H402 Harmful to aquatic life.

Precautionary statement(s)
P261 Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264 Wash skin thoroughly after handling.
P271 Use only outdoors or in a well-ventilated area.
P273 Avoid release to the environment.
P280 Wear eye protection/ face protection.
P280 Wear protective gloves.

P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P304 + P340 + P312	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/ physician if you feel unwell.
P305 + P351 + P338 + P310	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula	:	H_2CaO_2
Molecular weight	:	74.09 g/mol
CAS-No.	:	1305-62-0
EC-No.	:	215-137-3

Hazardous components

Component	Classification	Concentration
Calcium dihydroxide		
	Skin Irrit. 2; Eye Dam. 1; STOT SE 3; Aquatic Acute 3; H315, H318, H335, H402	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Air and moisture sensitive. Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Calcium dihydroxide	1305-62-0	TWA	5 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract irritation Eye irritation Skin irritation		
		TWA	5.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Eye irritation Skin irritation		

		TWA	15.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	5.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	5.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		PEL	5 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance — Form: powder
Colour: beige

b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	12.4 - 12.6 at 20 °C (68 °F)
e)	Melting point/freezing point	>= 450 °C (>= 842 °F)
f)	Initial boiling point and boiling range	No data available
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	The product is not flammable.
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	2.24 g/cm3 at 25 °C (77 °F)
n)	Water solubility	0.99 g/l at 20 °C (68 °F)
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	The substance or mixture is not classified as oxidizing.

9.2 Other safety information

Bulk density	200 - 800 kg/m3

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong acids

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Calcium oxide
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - 7,340 mg/kg

Inhalation: No data available

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: Irritating to skin.
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Severe eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
Inhalation - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: EW2800000

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Clarias gariepinus - 33.884 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates	EC50 - Daphnia magna (Water flea) - 49.1 mg/l - 48 h (OECD Test Guideline 202)
Toxicity to algae	EC50 - Pseudokirchneriella subcapitata (green algae) - 184.6 mg/l - 72 h (OECD Test Guideline 201)

12.2 Persistence and degradability

The methods for determining biodegradability are not applicable to inorganic substances.

12.3 Bioaccumulative potential
Does not bioaccumulate.

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Harmful to aquatic life.

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Calcium dihydroxide	1305-62-0	1994-04-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Calcium dihydroxide	1305-62-0	1994-04-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Calcium dihydroxide	1305-62-0	1994-04-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Eye Dam.	Serious eye damage
H315	Causes skin irritation.
H318	Causes serious eye damage.
H335	May cause respiratory irritation.
H402	Harmful to aquatic life.
Skin Irrit.	Skin irritation
STOT SE	Specific target organ toxicity - single exposure

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	2
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.10 Revision Date: 10/03/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.9
Revision Date 12/11/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Calcium carbonate

Product Number : C4830
Brand : Sigma-Aldrich

CAS-No. : 471-34-1

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : $CCaO_3$
Molecular weight : 100.09 g/mol
CAS-No. : 471-34-1
EC-No. : 207-439-9

Hazardous components

Component	Classification	Concentration
Calcium carbonate		
		90 - 100 %

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

hygroscopic Keep in a dry place.
Storage class (TRGS 510): 13: Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Calcium carbonate	471-34-1	TWA	10.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		TWA	15.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	5.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	5.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	10.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		PEL	10 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		PEL	5 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		TWA	5 mg/m3	USA. NIOSH Recommended Exposure Limits
	Remarks	Occurs in nature as as limestone, chalk, marble, dolomite, aragonite, calcite & oyster shells.		
		TWA	10 mg/m3	USA. NIOSH Recommended Exposure Limits
		Occurs in nature as as limestone, chalk, marble, dolomite, aragonite, calcite & oyster shells.		

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374

If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder Colour: white
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	8.0
e)	Melting point/freezing point	Melting point/freezing point: 800 °C (1,472 °F) - Decomposes on heating.
f)	Initial boiling point and boiling range	No data available
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	2.93 g/cm3 at 25 °C (77 °F)
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Exposure to moisture may affect product quality.

10.5 Incompatible materials
Strong oxidizing agents, Acids, Magnesium, Aluminium

10.6 Hazardous decomposition products
Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Calcium oxide
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - 6,450 mg/kg

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: FF9335000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

12.2 Persistence and degradability

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Calcium carbonate	471-34-1	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Calcium carbonate	471-34-1	

16. OTHER INFORMATION

HMIS Rating
Health hazard: 0

Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.9 Revision Date: 12/11/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.12
Revision Date 09/20/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Calcium oxide

Product Number : 451711
Brand : Aldrich

CAS-No. : 1305-78-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Serious eye damage (Category 1), H318
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H315	Causes skin irritation.
H318	Causes serious eye damage.
H335	May cause respiratory irritation.

Precautionary statement(s)

P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P280	Wear eye protection/ face protection.
P280	Wear protective gloves.
P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P304 + P340 + P312	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/ physician if

	you feel unwell.
P305 + P351 + P338 + P310	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

Reacts with water to form corrosive calcium hydroxide, with evolution of heat. Temperatures as high as 800° C have been reached with

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms	:	Quicklime Lime
Formula	:	CaO
Molecular weight	:	56.08 g/mol
CAS-No.	:	1305-78-8
EC-No.	:	215-138-9

Hazardous components

Component	Classification	Concentration
Calcium oxide		
	Skin Irrit. 2; Eye Dam. 1; STOT SE 3; H315, H318, H335	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.Continue rinsing eyes during transport to hospital.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols.Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Calcium oxide	1305-78-8	TWA	2 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract irritation		
		TWA	2.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation		

		TWA	5.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	2.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		PEL	2 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder Colour: white
b)	Odour	No data available
c)	Odour Threshold	No data available

d)	pH	12.5 - 12.8 at 1.65 g/l at 25 °C (77 °F)
e)	Melting point/freezing point	Melting point/range: 2,614 °C (4,737 °F)
f)	Initial boiling point and boiling range	2,850 °C (5,162 °F) - lit.
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	3.3 g/mL at 25 °C (77 °F)
n)	Water solubility	soluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Avoid moisture.

10.5 Incompatible materials
acids, Water

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Calcium oxide
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
Skin - Human
Result: Severe skin irritation

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Risk of serious damage to eyes.
(OECD Test Guideline 405)

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
Inhalation - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: EW3100000

Cough, Shortness of breath, Headache, Nausea, Vomiting
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Cyprinus carpio (Carp) - 1,070 mg/l - 96 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
UN number: 1910 Class: 8 Packing group: III
Proper shipping name: Calcium oxide

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Calcium oxide	1305-78-8	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Calcium oxide	1305-78-8	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
Calcium oxide	1305-78-8	1993-04-24

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Eye Dam.	Serious eye damage
H315	Causes skin irritation.
H318	Causes serious eye damage.
H335	May cause respiratory irritation.
Skin Irrit.	Skin irritation
STOT SE	Specific target organ toxicity - single exposure

HMIS Rating
Health hazard: 3

Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	3
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.12 Revision Date: 09/20/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 3.11
Revision Date 05/23/2016
Print Date 04/05/2019

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Cobalt

Product Number : 697745
Brand : Aldrich

CAS-No. : 7440-48-4

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Respiratory sensitisation (Category 1), H334
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)
H334 May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H410 Very toxic to aquatic life with long lasting effects.

Precautionary statement(s)
P261 Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P273 Avoid release to the environment.
P285 In case of inadequate ventilation wear respiratory protection.
P304 + P341 IF INHALED: If breathing is difficult, remove victim to fresh air and keep at rest in a position comfortable for breathing.
P342 + P311 If experiencing respiratory symptoms: Call a POISON CENTER/doctor.
P391 Collect spillage.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.2 Mixtures

Synonyms : Carbon coated cobalt nanoparticles
magnetic cobalt

Formula : Co
Molecular weight : 58.93 g/mol

Hazardous components

Component		Classification	Concentration
Cobalt			
CAS-No. EC-No. Index-No.	7440-48-4 231-158-0 027-001-00-9	Resp. Sens. 1; Skin Sens. 1; Aquatic Chronic 4; H317, H334, H413	<= 100 %
Graphene-like carbon			
		Eye Irrit. 2A; STOT SE 3; H319, H335	>= 5 - < 10 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up

Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections

For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid formation of dust and aerosols.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place.

Heat sensitive. Keep in a dry place.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Cobalt	7440-48-4	TWA	0.100000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	0.020000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Pulmonary function Asthma Myocardial effects Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Confirmed animal carcinogen with unknown relevance to humans		

		TWA	0.050000 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	0.100000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	0.050000 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	0.050000 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	0.050000 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	0.020000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Pulmonary function Asthma Myocardial effects Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Confirmed animal carcinogen with unknown relevance to humans varies		
		TWA	0.05 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	0.05 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	0.1 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	0.02 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Pulmonary function Asthma Myocardial effects Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Confirmed animal carcinogen with unknown relevance to humans varies		
		PEL	0.02 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

Biological occupational exposure limits

Component	CAS-No.	Parameters	Value	Biological specimen	Basis
Cobalt	7440-48-4	Cobalt	15.0000 µg/l	Urine	ACGIH - Biological Exposure Indices (BEI)
	Remarks	End of shift at end of workweek			
		Cobalt	1.0000 µg/l	In blood	ACGIH - Biological Exposure Indices (BEI)
		End of shift at end of workweek			
		Cobalt	15 µg/l	Urine	ACGIH - Biological Exposure Indices (BEI)
		End of shift at end of workweek			
		Cobalt		Urine	ACGIH - Biological Exposure Indices (BEI)
		End of shift at end of workweek			

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particle respirator.For higher level protection use type OV/AG/P99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	No data available
f)	Initial boiling point and boiling range	2,900 °C (5,252 °F) - lit.
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	8.9 g/mL at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available

r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Oxidizing agents, Strong oxidizing agents, Acetylene, Material readily reacts with acids generating flammable and/or explosive hydrogen gas., Mineral acids, Hydrazinium nitrate

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides, Cobalt/cobalt oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC:	2B - Group 2B: Possibly carcinogenic to humans (Cobalt)
	2A - Group 2A: Probably carcinogenic to humans (Cobalt)
IARC:	2B - Group 2B: Possibly carcinogenic to humans (Cobalt)
	2A - Group 2A: Probably carcinogenic to humans (Cobalt)
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

Kidney injury may occur., Damage to the eyes., Lung irritation, chest pain, pulmonary edema, May cause irritation of the:, nose, Throat., sensation of heat

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Very toxic to aquatic life.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 3089 Class: 4.1 Packing group: II
Proper shipping name: Metal powders, flammable, n.o.s.

Poison Inhalation Hazard: No

IMDG
UN number: 3089 Class: 4.1 Packing group: II EMS-No: F-G, S-G
Proper shipping name: METAL POWDER, FLAMMABLE, N.O.S.

IATA
UN number: 3089 Class: 4.1 Packing group: II
Proper shipping name: Metal powder, flammable, n.o.s.

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01

SARA 311/312 Hazards
Fire Hazard, Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01
Graphene-like carbon	-	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Cobalt	7440-48-4	2007-07-01
Graphene-like carbon	-	

California Prop. 65 Components

	CAS-No.	Revision Date
WARNING! This product contains a chemical known to the State of California to cause cancer.	7440-48-4	2007-09-28
Cobalt		

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Chronic	Chronic aquatic toxicity
Eye Irrit.	Eye irritation
H317	May cause an allergic skin reaction.
H319	Causes serious eye irritation.
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H335	May cause respiratory irritation.
H400	Very toxic to aquatic life.
H410	Very toxic to aquatic life with long lasting effects.
H413	May cause long lasting harmful effects to aquatic life.
Resp. Sens.	Respiratory sensitisation
Skin Sens.	Skin sensitisation

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	*
Flammability:	3
Physical Hazard	3

NFPA Rating

Health hazard:	2
Fire Hazard:	3
Reactivity Hazard:	3

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.11 Revision Date: 05/23/2016 Print Date: 04/05/2019

SAFETY DATA SHEET

Version 3.7
Revision Date 09/22/2017
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Silicon dioxide

Product Number : 85356
Brand : Aldrich

CAS-No. : 60676-86-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms : Silica
Quartz
Sand
Cristobalite

Formula : O_2Si
Molecular weight : 60.08 g/mol
CAS-No. : 60676-86-0

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: crystalline Colour: beige
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	9.0 - 11.0 at 20 g/l at 20 °C (68 °F)
e)	Melting point/freezing point	Melting point/range: 1,610 °C (2,930 °F)

f)	Initial boiling point and boiling range	No data available
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	2.6 g/mL at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	370 °C (698 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information

Bulk density	480 - 600 kg/m3

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - silicon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - > 5,000 mg/kg

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Silicon dioxide	-	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Silicon dioxide	-	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.7 Revision Date: 09/22/2017 Print Date: 11/10/2018

SAFETY DATA SHEET

Version 4.8
Revision Date 05/24/2016
Print Date 10/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Chromium(III) oxide

Product Number : 634239
Brand : Aldrich

CAS-No. : 1308-38-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms : Chromia

Formula : Cr_2O_3
Molecular weight : 151.99 g/mol
CAS-No. : 1308-38-9
EC-No. : 215-160-9

Hazardous components

Component	Classification	Concentration
Chromium (III) oxide		
		<= 100 %

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

hygroscopic Handle and store under inert gas. Keep in a dry place.
Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Chromium (III) oxide	1308-38-9	TWA	0.500000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	1.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	0.500000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract irritation Skin irritation Not classifiable as a human carcinogen varies		
		TWA	0.500000 mg/m3	USA. NIOSH Recommended Exposure Limits
		Chromium(III) compounds include soluble chromic salts. See Appendix C		
		TWA	1.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	0.5 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	0.5 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Skin irritation Not classifiable as a human carcinogen varies		
		TWA	0.5 mg/m3	USA. NIOSH Recommended Exposure Limits
		Chromium(III) compounds include soluble chromic salts. See Appendix C		
		PEL	0.5 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		see Sections 1532.2, 5206 & 8359		

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder Colour: green
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/freezing point: 2,435 °C (4,415 °F)
f)	Initial boiling point and boiling range	4,000 °C (7,232 °F)
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	5.210 g/cm3
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Avoid moisture.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Chromium oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male - > 15,000 mg/kg
(OECD Test Guideline 401)

LC50 Inhalation - Rat - male and female - 4 h - > 5.41 mg/l
(OECD Test Guideline 403)

Dermal: No data available

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: Mild skin irritation

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Mild eye irritation

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
OECD Test Guideline 474
Mouse - male and female
Result: negative

Carcinogenicity

This product is or contains a component that is not classifiable as to its carcinogenicity based on its IARC, ACGIH, NTP, or EPA classification.

IARC:	3 - Group 3: Not classifiable as to its carcinogenicity to humans (Chromium (III) oxide)
IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information

Repeated dose toxicity	Rat - male and female - NOAEL : 2,000 mg/kg

RTECS: GB6475000

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	static test LC50 - Danio rerio (zebra fish) - > 10,000 mg/l - 96 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA

Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
Chromium (III) oxide	1308-38-9	1994-04-01

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Chromium (III) oxide	1308-38-9	1994-04-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Chromium (III) oxide	1308-38-9	1994-04-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
Chromium (III) oxide	1308-38-9	1994-04-01

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.8 Revision Date: 05/24/2016 Print Date: 10/19/2018

SAFETY DATA SHEET

Version 4.7
Revision Date 10/08/2015
Print Date 10/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Iron(II,III) oxide

Product Number : 637106
Brand : Aldrich

CAS-No. : 1317-61-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms : Magnetite

Formula : Fe_3O_4
Molecular weight : 231.53 g/mol
CAS-No. : 1317-61-9
EC-No. : 215-277-5

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Iron oxides

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

Keep in a dry place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: powder, Spheres Colour: black
b)	Odour	odourless
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 1,538 °C (2,800 °F) - lit.
f)	Initial boiling point and boiling range	No data available
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	4.8 - 5.1 g/mL at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available

t) Oxidizing properties No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong acids, Peroxides, Chloroformates

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male and female - > 5,000 mg/kg

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: No eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
- Guinea pig
Result: Did not cause sensitisation on laboratory animals.

Germ cell mutagenicity
Hamster
Lungs
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a

carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components

This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Triiron tetraoxide	1317-61-9	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Triiron tetraoxide	1317-61-9	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating

Health hazard:	0
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	0
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.7 Revision Date: 10/08/2015 Print Date: 10/19/2018

SAFETY DATA SHEET

Version 5.12
Revision Date 08/01/2018
Print Date 11/10/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Sodium chloride

Product Number : S7653
Brand : Sigma-Aldrich

CAS-No. : 7647-14-5

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : NaCl
Molecular weight : 58.44 g/mol
CAS-No. : 7647-14-5
EC-No. : 231-598-3
Registration number : 01-2119485491-33-XXXX

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid formation of dust and aerosols.Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Storage class (TRGS 510): 13: Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	7
e)	Melting point/freezing	Melting point/range: 801 °C (1,474 °F)

	point	
f)	Initial boiling point and boiling range	1,413 °C (2,575 °F)
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	1.33 hPa (1.00 mmHg) at 865 °C (1,589 °F)
l)	Vapour density	No data available
m)	Relative density	2.1650 g/cm3
n)	Water solubility	358 g/l at 20 °C (68 °F) - soluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Hydrogen chloride gas, Sodium oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity

LD50 Oral - Rat - 3,550 mg/kg

LC50 Inhalation - Rat - 1 h - > 42,000 mg/m3

LD50 Dermal - Rabbit - > 10,000 mg/kg

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

No data available

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity

No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: VZ4725000

Vomiting, Diarrhoea, Dehydration and congestion may occur in internal organs. Hypertonic salt solutions can produce inflammatory reactions in the gastrointestinal tract., To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated., Nausea

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Lepomis macrochirus (Bluegill) - 5,840 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates	NOEC - Daphnia (water flea) - 1,500 mg/l - 7 d
	LC50 - Daphnia magna (Water flea) - 1,661 mg/l - 48 h

12.2 Persistence and degradability

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Sodium chloride	7647-14-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Sodium chloride	7647-14-5	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.12 Revision Date: 08/01/2018 Print Date: 11/10/2018

Appendix D

ASPEN Plus V.10 Simulation Reports

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ASPEN PLUS CALCULATION REPORT

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HOTLINE:
U.S.A. 888/996-7100
EUROPE (44) 1189-226555

PLATFORM: WINDOWS
VERSION: 36.0 Build 250 Patchlevel 1
INSTALLATION:

APRIL 15, 2019
MONDAY
2:27:02 P.M.

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TABLE OF CONTENTS

RUN CONTROL SECTION

RUN CONTROL INFORMATION

THIS COPY OF ASPEN PLUS LICENSED TO UNIVERSITY OF PENNSYLVAN

TYPE OF RUN: NEW

INPUT FILE NAME: _2351ipc.inm

OUTPUT PROBLEM DATA FILE NAME: _2351ipc
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:
  NUMBER OF FILE RECORDS (PSIZE) =   0
  NUMBER OF IN-CORE RECORDS   =   256
PSIZE NEEDED FOR SIMULATION   =   256

CALLING PROGRAM NAME: apmain
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V10.0\Engine\\xeq

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
AIRIN	----	SCRUBBER	SCRUBH2O	----	KOHMIX
KOHFEED	----	KOHMIX	CAOH2FED	----	CAOH2MIX
CAPRCIN	----	RECSPL	HYDH2OC	----	H2OHYD1
CAHYDCWI	----	CAHYDRHX	CAOHXCWI	----	CAOHX
SATWATER	----	SATFLASH	SATAIR	----	SATFLASH
WETCAKEW	----	CACO3WC	CARECWTR	----	CAOH2REC
HYDPRODS	HYDRATOR	CAOH2SPL	SCRUBOUT	SCRUBBER	AIRSEP
PELLTOUT	PELLETRX	CACO3SPL	KILNOUTH	KILN	CAOCO2SP
KOHSOLLP	KOHMIX	KOHPUMP	KILNFEED	KILNHT	KILN
CAOH2IN	CAOH2MIX	PELLMIX	CAOH2PRG	CAOH2SPL	----
CAOH2H	CAOH2SPL	H2OHYD1	KOHPURGE	KOHSPLIT	----
KOHRECIN	KOHSPLIT	KOHMIX	CARECIN	RECSPL	CAOH2MIX
CARECPRG	RECSPL	----	KOHREC	KCACENT	KOHSPLIT
CAPRCOUT	KCACENT	----	CAOH2WRM	H2OHYD1	CAOH2REC
HYDH2OW	H2OHYD1	H2OHYD2	CAHYDC	CAHYDRHX	CAOH2MIX
CAHYDCWO	CAHYDRHX	----	CAOHOT	CAOHX	HYDRATOR
CAOHXCWO	CAOHX	----	CO2PROD	SCREWHX	----
CO3HXHTR	SCREWHX	SCREWHTR	AIRVENT	AIRSEP	----
LIQOUT	AIRSEP	PELLMIX	PELPRODO	CACO3SPL	KCACENT
CACO3O	CACO3SPL	CACO3WC	CO2HOT	CAOCO2SP	SCREWHX
CAOOUT	CAOCO2SP	CAOHX	SATVAPOR	SATFLASH	----
SATLIQUI	SATFLASH	----	KOHSOLHP	KOHPUMP	SCRUBBER
CO3LIQO	CO3FLASH	----	CO3HTDRY	CO3FLASH	KILNHT
CO3TOHT	CACO3WC	SCREWHX	CO3TOFLS	SCREWHTR	CO3FLASH
CAOH2WHP	CAPUMP	CAHYDRHX	CAOH2WLP	CAOH2REC	CAPUMP
PELLFEED	PELLMIX	PELLETRX	HYDH2OH	H2OHYD2	HYDRATOR

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
HYDRATOR	CAOHOT HYDH2OH	HYDPRODS
SCRUBBER	AIRIN KOHSOLHP	SCRUBOUT
PELLETRX	PELLFEED	PELLTOUT
KILN	KILNFEED	KILNOUTH
KOHMIX	KOHFEED KOHRECIN SCRUBH2O	KOHSOLLP
KILNHT	CO3HTDRY	KILNFEED
CAOH2MIX	CAOH2FED CARECIN CAHYDC	CAOH2IN
CAOH2SPL	HYDPRODS	CAOH2PRG CAOH2H

```
  KOHSPLIT     KOHREC                          KOHPURGE KOHRECIN
  RECSPL       CAPRCIN                         CARECIN CARECPRG
  KCACENT      PELPRODO                        KOHREC CAPRCOUT
  H2OHYD1      CAOH2H HYDH2OC                  CAOH2WRM HYDH2OW
  CAHYDRHX     CAOH2WHP CAHYDCWI               CAHYDC CAHYDCWO
  CAOHX        CAOOUT CAOHXCWI                 CAOHOT CAOHXCWO
  SCREWHX      CO2HOT CO3TOHT                  CO2PROD CO3HXHTR
  AIRSEP       SCRUBOUT                        AIRVENT LIQOUT
  CACO3SPL     PELLTOUT                        PELPRODO CACO3O
  CAOCO2SP     KILNOUTH                        CO2HOT CAOOUT
  SATFLASH     SATAIR SATWATER                 SATVAPOR SATLIQUI
  KOHPUMP      KOHSOLLP                        KOHSOLHP
  CO3FLASH     CO3TOFLS                        CO3LIQO CO3HTDRY
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                 04/15/2019  PAGE 3

                              FLOWSHEET SECTION

 FLOWSHEET CONNECTIVITY BY BLOCKS (CONTINUED)
  CACO3WC      CACO3O WETCAKEW                 CO3TOHT
  SCREWHTR     CO3HXHTR                        CO3TOFLS
  CAPUMP       CAOH2WLP                        CAOH2WHP
  CAOH2REC     CAOH2WRM CARECWTR               CAOH2WLP
  PELLMIX      LIQOUT CAOH2IN                  PELLFEED
  H2OHYD2      HYDH2OW                         HYDH2OH

 CONVERGENCE STATUS SUMMARY
 --------------------------

  DESIGN-SPEC SUMMARY
  ===================


  DESIGN                                                              CONV
  SPEC      ERROR        TOLERANCE    ERR/TOL      VARIABLE   STAT  BLOCK
  ------    -----        ---------    -------      --------   ----  -----
  CAHYDHX  -0.50002E-05  0.10000E-02 -0.50002E-02  0.11450E+06 #    $OLVER01
  CAOHXCW  -0.98378E-03  0.10000E-02 -0.98378      0.88872E+06 #    $OLVER02
  CARECH2O -0.11902E-04  0.10000E-02 -0.11902E-01   3158.4     #    $OLVER03

  TEAR STREAM SUMMARY
  ===================


  STREAM    VARIABLE         MAXIMUM      MAX. ERR.    ABSOLUTE          CONV
  ID        ID               ERR/TOL      RELATIVE     ERROR       STAT  BLOCK
  ------    --------         --------     -------      ---------   ----  -----
  KILNOUTH TOTAL MOLEFLOW    0.46285E-08 -0.92569E-12  0.18491E-12  #
  CDECOUT

  HYDH2OH  WATER MOLEFLOW    0.28510E-06  0.28510E-10  0.62645E-11  #
  CH2OHOT

  KOHSOLHP CAOH2(S)MOLEFLOW  0.96749     -0.19350E-03  0.42907E-10  #
  CKOHFEED

  PELLTOUT CACO3(S)MOLEFLOW  0.39540      0.19770E-03  0.10047E-03  #
  CPELLOUT


  #  = CONVERGED
  *  = NOT CONVERGED
  LB = AT LOWER BOUNDS
  UB = AT UPPER BOUNDS

 DESIGN-SPEC:  CAHYDHX
 ---------------------
```

```
  SAMPLED VARIABLES:
    CWOUT    : TEMPERATURE IN STREAM CAHYDCWO SUBSTREAM MIXED

  SPECIFICATION:
    MAKE CWOUT APPROACH 15.0000
    WITHIN          0.00100000

  MANIPULATED VARIABLES:
    VARY     : WATER MASSFLOW IN STREAM CAHYDCWI SUBSTREAM MIXED
    LOWER LIMIT =      55,115.6                     LB/HR
    UPPER LIMIT =     165,347.                      LB/HR
    FINAL VALUE =     114,503.                      LB/HR
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                              FLOWSHEET SECTION

 DESIGN-SPEC:  CAHYDHX (CONTINUED)

  VALUES OF ACCESSED FORTRAN VARIABLES:
    VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                     OF LOOP
    --------      --------------      -----------     -----
    CWOUT           15.0000            15.0000       C

 DESIGN-SPEC:  CAOHXCW
 ---------------------

  SAMPLED VARIABLES:
    CWOUT    : TEMPERATURE IN STREAM CAOHXCWO SUBSTREAM MIXED

  SPECIFICATION:
    MAKE CWOUT APPROACH 48.8900
    WITHIN          0.00100000

  MANIPULATED VARIABLES:
    VARY     : WATER MASSFLOW IN STREAM CAOHXCWI SUBSTREAM MIXED
    LOWER LIMIT =     220,462.                      LB/HR
    UPPER LIMIT =   2,425,080.                      LB/HR
    FINAL VALUE =     888,715.                      LB/HR

  VALUES OF ACCESSED FORTRAN VARIABLES:
    VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                     OF LOOP
    --------      --------------      -----------     -----
    CWOUT           48.8890            48.8890       C

 DESIGN-SPEC:  CARECH2O
 ----------------------

  SAMPLED VARIABLES:
    MASSFRAC : WATER MASSFRAC IN STREAM CAOH2WLP SUBSTREAM MIXED

  SPECIFICATION:
    MAKE MASSFRAC APPROACH 0.050000
    WITHIN          0.00100000

  MANIPULATED VARIABLES:
    VARY     : TOTAL MASSFLOW IN STREAM CARECWTR SUBSTREAM MIXED
    LOWER LIMIT =           0.50000                 LB/HR
    UPPER LIMIT =      10,000.0                     LB/HR
    FINAL VALUE =       3,158.42                    LB/HR

  VALUES OF ACCESSED FORTRAN VARIABLES:
    VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                     OF LOOP
```

MASSFRAC	0.499881E-01	0.499881E-01	

FLOWSHEET SECTION

TRANSFER BLOCK: CAPELREC

EQUAL-TO : STREAM IN STREAM CAPRCOUT
SET : STREAM IN STREAM CAPRCIN

CALCULATOR BLOCK: CAOHSPEC

SAMPLED VARIABLES:
CAFEED : CAOH2(S)MOLEFLOW IN STREAM CAOH2FED SUBSTREAM MIXED
CAHYDRC : CAOH2(S)MOLEFLOW IN STREAM CAOH2H SUBSTREAM MIXED
CARXNREC : CAOH2(S)MOLEFLOW IN STREAM CARECIN SUBSTREAM MIXED
K2CO3FD : K2CO3(S)MOLEFLOW IN STREAM LIQOUT SUBSTREAM CISOLID

FORTRAN STATEMENTS:

```
CAFEED = K2CO3FD - (CAHYDREC + CARXNREC)
```

READ VARIABLES: CAHYDRC CARXNREC K2CO3FD

WRITE VARIABLES: CAFEED

VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:

VARIABLE	VALUE READ	VALUE WRITTEN	UNITS
CAFEED	156.936	157.612	KMOL/HR
CAHYDRC	683.135		KMOL/HR
CARXNREC	561.490		KMOL/HR
K2CO3FD	719.103		KMOL/HR

CALCULATOR BLOCK: CAOWATER

SAMPLED VARIABLES:
HYDH2OFD : WATER MOLEFLOW IN STREAM HYDH2OC SUBSTREAM MIXED
CAOPRODS : CAO MOLEFLOW IN STREAM CAOHOT SUBSTREAM CISOLID

FORTRAN STATEMENTS:

```
HYDH2OFD = 1.1*CAOPRODS
```

READ VARIABLES: CAOPRODS

WRITE VARIABLES: HYDH2OFD

VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:

VARIABLE	VALUE READ	VALUE WRITTEN	UNITS
HYDH2OFD	791.013	791.013	KMOL/HR
CAOPRODS	719.103		KMOL/HR

FLOWSHEET SECTION

CALCULATOR BLOCK: CO3HTRS

SAMPLED VARIABLES:
TCO3 : TEMPERATURE IN STREAM CO3HXHTR SUBSTREAM CISOLID
TSCREWHT : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK SCREWHTR
TFLASH : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK CO3FLASH

```
     FORTRAN STATEMENTS:
           IF(TCO3 .LT. 250) TSCREWHT = 250
           IF(TCO3 .GE. 250) TSCREWHT = TCO3

           TFLASH = TSCREWHT

     READ VARIABLES:  TCO3

     WRITE VARIABLES: TSCREWHT  TFLASH

     VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:
       VARIABLE        VALUE READ      VALUE WRITTEN    UNITS
       --------        ----------      -------------    -----
       TCO3             269.542                         C
       TSCREWHT         269.542          269.542        C
       TFLASH           269.542          269.542        C

  CALCULATOR BLOCK:   HUMIDITY
  ----------------------------

     SAMPLED VARIABLES:
       WFRAC    : WATER MOLEFRAC IN STREAM SATVAPOR SUBSTREAM MIXED
       WATERIN  : WATER MOLEFLOW IN STREAM AIRIN SUBSTREAM MIXED
       N2IN     : N2 MOLEFLOW IN STREAM AIRIN SUBSTREAM MIXED
       O2IN     : O2 MOLEFLOW IN STREAM AIRIN SUBSTREAM MIXED
       CO2IN    : CO2 MOLEFLOW IN STREAM AIRIN SUBSTREAM MIXED
       N2FRAC   : PARAMETER 104
       O2FRAC   : PARAMETER 105
       CO2FRAC  : PARAMETER 106
       AIRFLOW  : PARAMETER 103
       N2FRAC2  : LOCAL-PARAM
       O2FRAC2  : LOCAL-PARAM
       CO2FRAC2 : LOCAL-PARAM
       LIQRATIO : PARAMETER 101
       KOHFRAC  : PARAMETER 102
       HUMIDITY : PARAMETER 201

     FORTRAN STATEMENTS:
     C
     C
           TOTAL = N2FRAC+O2FRAC+CO2FRAC+(WFRAC*HUMIDITY)
           N2FRAC2 = N2FRAC/TOTAL
           O2FRAC2 = O2FRAC/TOTAL
           CO2FRAC2 = CO2FRAC/TOTAL
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                                FLOWSHEET SECTION

  CALCULATOR BLOCK:   HUMIDITY (CONTINUED)
           WFRAC2 = WFRAC/TOTAL

           N2IN = N2FRAC*AIRFLOW
           O2IN = O2FRAC*AIRFLOW
           CO2IN = CO2FRAC*AIRFLOW
           WATERIN = WFRAC2*AIRFLOW*HUMIDITY

     READ VARIABLES:  WFRAC     N2FRAC    O2FRAC    CO2FRAC   LIQRATIO
KOHFRAC   HUMIDITY

     WRITE VARIABLES: WATERIN   N2IN      O2IN      CO2IN     AIRFLOW
CO2FRAC2  O2FRAC2   N2FRAC2

     VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:
       VARIABLE        VALUE READ      VALUE WRITTEN    UNITS
       --------        ----------      -------------    -----
       WFRAC           0.320765E-01
```

WATERIN	0.00000	57044.0	KMOL/HR
N2IN	0.188051E+07	0.189316E+07	KMOL/HR
O2IN	499532.	502892.	KMOL/HR
CO2IN	952.397	958.804	KMOL/HR
N2FRAC	0.789800		
O2FRAC	0.209800		
CO2FRAC	0.400000E-03		
AIRFLOW	0.239701E+07	0.239701E+07	
N2FRAC2	MISSING	0.771004	
O2FRAC2	MISSING	0.204807	
CO2FRAC2	MISSING	0.390481E-03	
LIQRATIO	4.50000		
KOHFRAC	0.500000		
HUMIDITY	0.760000		

CALCULATOR BLOCK: INPUTS

****

*

* WARNING(S) IN BLOCK CALCULATIONS *

*

****

SAMPLED VARIABLES:

N2FRAC : PARAMETER 104
O2FRAC : PARAMETER 105
CO2FRAC : PARAMETER 106
AIRTEMP : TEMPERATURE IN STREAM AIRIN SUBSTREAM MIXED
AIRTEMP2 : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK SATFLASH
AIRFLOW : PARAMETER 103
LIQRATIO : PARAMETER 101
KOHFRAC : PARAMETER 102
HUMIDITY : PARAMETER 201
WETCAKE : PARAMETER 202

FORTRAN STATEMENTS:

FLOWSHEET SECTION

CALCULATOR BLOCK: INPUTS (CONTINUED)

```
C
C
      AIRTEMP = 25
      AIRTEMP2 = AIRTEMP
      HUMIDITY = 0.76
      AIRFLOW = 2397009

      N2FRAC = 0.7898
      O2FRAC = 0.2098
      CO2FRAC = 0.0004
      TOTAL = N2FRAC+O2FRAC+CO2FRAC+(WFRAC*HUMIDITY)
      N2FRAC2 = N2FRAC/TOTAL
      O2FRAC2 = O2FRAC/TOTAL
      CO2FRAC2 = CO2FRAC/TOTAL
      WFRAC2 = WFRAC/TOTAL

      N2IN = N2FRAC*AIRFLOW
      O2IN = O2FRAC*AIRFLOW
      CO2IN = CO2FRAC*AIRFLOW
      WATERIN = WFRAC2*AIRFLOW*HUMIDITY

      LIQRATIO = 4.5
      KOHFRAC = 0.5
```

```
          WETCAKE = 0.05

    WRITE VARIABLES: N2FRAC    O2FRAC    CO2FRAC   AIRTEMP   AIRTEMP2
  AIRFLOW   LIQRATIO  KOHFRAC   HUMIDITY  WETCAKE

    VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:
      VARIABLE        VALUE READ      VALUE WRITTEN    UNITS
      --------        ----------      -------------    -----
      N2FRAC           MISSING         0.789800
      O2FRAC           MISSING         0.209800
      CO2FRAC          MISSING         0.400000E-03
      AIRTEMP          27.0000          25.0000        C
      AIRTEMP2         25.0000          25.0000        C
      AIRFLOW          MISSING         0.239701E+07
      LIQRATIO         MISSING          4.50000
      KOHFRAC          MISSING         0.500000
      HUMIDITY         MISSING         0.760000
      WETCAKE          MISSING         0.500000E-01

 CALCULATOR BLOCK:   KOHH2O
 --------------------------

    SAMPLED VARIABLES:
      H2OIN    : TOTAL MASSFLOW IN STREAM SCRUBH2O SUBSTREAM MIXED
      KOHIN    : TOTAL MASSFLOW IN STREAM KOHFEED SUBSTREAM MIXED
      KREC     : K+ MASSFLOW IN STREAM KOHRECIN SUBSTREAM MIXED
      H2OREC   : WATER MASSFLOW IN STREAM KOHRECIN SUBSTREAM MIXED
      AIRIN    : TOTAL MASSFLOW IN STREAM AIRIN SUBSTREAM MIXED
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                              FLOWSHEET SECTION

 CALCULATOR BLOCK:   KOHH2O (CONTINUED)
      LIQRATIO : PARAMETER 101
      SBLIQ    : LOCAL-PARAM
      KOHFRAC  : PARAMETER 102
      OHREC    : OH- MASSFLOW IN STREAM KOHRECIN SUBSTREAM MIXED

    FORTRAN STATEMENTS:
          SBLIQ = AIRIN/LIQRATIO
          WATERIN = SBLIQ*(1-KOHFRAC)-H2OREC

          KOHIN = SBLIQ*KOHFRAC - KREC - OHREC

    READ VARIABLES:  OHREC     KOHFRAC   KREC      H2OREC    AIRIN
  LIQRATIO

    WRITE VARIABLES: H2OIN     KOHIN     SBLIQ

    VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:
      VARIABLE        VALUE READ      VALUE WRITTEN    UNITS
      --------        ----------      -------------    -----
      H2OIN            20803.5          20803.5        KG/HR
      KOHIN            396629.          396607.        KG/HR
      KREC            0.522509E+07                    KG/HR
      H2OREC          0.101434E+08                    KG/HR
      AIRIN           0.701958E+08                    KG/HR
      LIQRATIO         4.50000
      SBLIQ           0.155991E+08     0.155991E+08
      KOHFRAC         0.500000
      OHREC           0.217783E+07                    KG/HR

 CALCULATOR BLOCK:   WETCAKEC
 ----------------------------

    SAMPLED VARIABLES:
```

```
      WETCAKE  : PARAMETER 202
      CACO3FLO : CACO3(S)MASSFLOW IN STREAM CACO3O SUBSTREAM CISOLID
      H2OFLOW  : TOTAL MASSFLOW IN STREAM WETCAKEW SUBSTREAM MIXED

    FORTRAN STATEMENTS:
         H2OFLOW = (WETCAKE*CACO3FLO)/(1-WETCAKE)

    READ VARIABLES:  WETCAKE   CACO3FLO

    WRITE VARIABLES: H2OFLOW

    VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:
      VARIABLE        VALUE READ      VALUE WRITTEN    UNITS
      --------        ----------      -------------    -----
      WETCAKE         0.500000E-01
      CACO3FLO         71973.0                         KG/HR
      H2OFLOW          3788.05          3788.05        KG/HR
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                                FLOWSHEET SECTION

 CONVERGENCE BLOCK:  CDECOUT
 ---------------------------
     Tear Stream  :  KILNOUTH
     Tolerance used:  0.200D-03
     Trace molefrac:  0.200D-05
     Trace substr-2:  0.200D-05

     MAXIT =   30 WAIT =   2
     METHOD: BROYDEN       STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:   314
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                            *** FINAL VALUES ***

VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------  -------- -------- -------- -------- -------- -----------
------------   ------------   ------------
   1  TOTAL MOLEFLOW   KILNOUTH MIXED                                 LBMOL/HR
   1585.3501      1585.3501     -4.6236-09
   2  TOTAL MOLEFLOW   KILNOUTH CISOLID                               LBMOL/HR
   1585.3501      1585.3501     -4.6285-09
   3  MOLE-FLOW        KILNOUTH MIXED    O2                           LBMOL/HR
   0.0            0.0         -5000.0000     T
   4  MOLE-FLOW        KILNOUTH MIXED    CO2                          LBMOL/HR
   1585.3501      1585.3501     -4.6236-09
   5  MOLE-FLOW        KILNOUTH MIXED    N2                           LBMOL/HR
   0.0            0.0         -5000.0000     T
   6  MOLE-FLOW        KILNOUTH MIXED    WATER                        LBMOL/HR
   0.0            0.0         -5000.0000     T
   7  MOLE-FLOW        KILNOUTH MIXED    KOH                          LBMOL/HR
   0.0            0.0             0.0
   8  MOLE-FLOW        KILNOUTH MIXED    K2CO3                        LBMOL/HR
   0.0            0.0             0.0
   9  MOLE-FLOW        KILNOUTH MIXED    CACO3                        LBMOL/HR
   0.0            0.0             0.0
  10  MOLE-FLOW        KILNOUTH MIXED    CAO                          LBMOL/HR
  0.0            0.0             0.0
  11  MOLE-FLOW        KILNOUTH MIXED    CA(OH)2                      LBMOL/HR
   0.0            0.0             0.0
  12  MOLE-FLOW        KILNOUTH MIXED    CA++                         LBMOL/HR
   0.0            0.0         -5000.0000     T
  13  MOLE-FLOW        KILNOUTH MIXED    H3O+                         LBMOL/HR
   0.0            0.0         -5000.0000     T
  14  MOLE-FLOW        KILNOUTH MIXED    CAOH+                        LBMOL/HR
```

```
      0.0             0.0             0.0
638   15  MOLE-FLOW         KILNOUTH MIXED    K+                            LBMOL/HR
      0.0             0.0         -5000.0000     T
639   16  MOLE-FLOW         KILNOUTH MIXED    KOH(S)                        LBMOL/HR
      0.0             0.0             0.0
640   17  MOLE-FLOW         KILNOUTH MIXED    KOH*W(S)                      LBMOL/HR
      0.0             0.0             0.0
641   18  MOLE-FLOW         KILNOUTH MIXED    KOH:2(S)                      LBMOL/HR
      0.0             0.0             0.0
642   19  MOLE-FLOW         KILNOUTH MIXED    CACO3(S)                      LBMOL/HR
      0.0             0.0             0.0
643   20  MOLE-FLOW         KILNOUTH MIXED    K2CO3(S)                      LBMOL/HR
      0.0             0.0             0.0
644   21  MOLE-FLOW         KILNOUTH MIXED    KHCO3(S)                      LBMOL/HR
      0.0             0.0             0.0
645   22  MOLE-FLOW         KILNOUTH MIXED    CAOH2(S)                      LBMOL/HR
      0.0             0.0             0.0
646   23  MOLE-FLOW         KILNOUTH MIXED    HCO3-                         LBMOL/HR
      0.0             0.0         -5000.0000     T
647   24  MOLE-FLOW         KILNOUTH MIXED    OH-                           LBMOL/HR
      0.0             0.0         -5000.0000     T
648   25  MOLE-FLOW         KILNOUTH MIXED    CO3--                         LBMOL/HR
      0.0             0.0         -5000.0000     T
649   26  PRESSURE          KILNOUTH MIXED                                  PSIA
      29.0075         29.0075          0.0
650   27  MASS ENTHALPY     KILNOUTH MIXED                                  BTU/LB
      -3453.8392      -3453.8392          0.0
651   28  MOLE-FLOW         KILNOUTH CISOLID  O2                            LBMOL/HR
      0.0             0.0             0.0
652   29  MOLE-FLOW         KILNOUTH CISOLID  CO2                           LBMOL/HR
      0.0             0.0             0.0
653   30  MOLE-FLOW         KILNOUTH CISOLID  N2                            LBMOL/HR
      0.0             0.0             0.0
654   31  MOLE-FLOW         KILNOUTH CISOLID  WATER                         LBMOL/HR
      0.0             0.0             0.0
655   32  MOLE-FLOW         KILNOUTH CISOLID  KOH                           LBMOL/HR
      0.0             0.0             0.0
656   33  MOLE-FLOW         KILNOUTH CISOLID  K2CO3                         LBMOL/HR
      0.0             0.0             0.0
657   34  MOLE-FLOW         KILNOUTH CISOLID  CACO3                         LBMOL/HR
      0.0             0.0             0.0
658   35  MOLE-FLOW         KILNOUTH CISOLID  CAO                           LBMOL/HR
      1585.3501       1585.3501      -4.6236-09
659   36  MOLE-FLOW         KILNOUTH CISOLID  CA(OH)2                       LBMOL/HR
      0.0             0.0             0.0
660   37  MOLE-FLOW         KILNOUTH CISOLID  CA++                          LBMOL/HR
      0.0             0.0             0.0
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662
663                                FLOWSHEET SECTION
664
665  CONVERGENCE BLOCK:  CDECOUT (CONTINUED)
666   38  MOLE-FLOW         KILNOUTH CISOLID  H3O+                          LBMOL/HR
      0.0             0.0             0.0
667   39  MOLE-FLOW         KILNOUTH CISOLID  CAOH+                         LBMOL/HR
      0.0             0.0             0.0
668   40  MOLE-FLOW         KILNOUTH CISOLID  K+                            LBMOL/HR
      0.0             0.0             0.0
669   41  MOLE-FLOW         KILNOUTH CISOLID  KOH(S)                        LBMOL/HR
      0.0             0.0         -5000.0000     T
670   42  MOLE-FLOW         KILNOUTH CISOLID  KOH*W(S)                      LBMOL/HR
      0.0             0.0             0.0
671   43  MOLE-FLOW         KILNOUTH CISOLID  KOH:2(S)                      LBMOL/HR
      0.0             0.0             0.0
672   44  MOLE-FLOW         KILNOUTH CISOLID  CACO3(S)                      LBMOL/HR
      0.0             0.0             0.0
```

```
673     45  MOLE-FLOW        KILNOUTH CISOLID  K2CO3(S)                    LBMOL/HR
        0.0         1.5434-12     -5000.0000     T
674     46  MOLE-FLOW        KILNOUTH CISOLID  KHCO3(S)                    LBMOL/HR
        0.0            0.0           0.0
675     47  MOLE-FLOW        KILNOUTH CISOLID  CAOH2(S)                    LBMOL/HR
        0.0            0.0        -5000.0000     T
676     48  MOLE-FLOW        KILNOUTH CISOLID  HCO3-                       LBMOL/HR
        0.0            0.0           0.0
677     49  MOLE-FLOW        KILNOUTH CISOLID  OH-                         LBMOL/HR
        0.0            0.0           0.0
678     50  MOLE-FLOW        KILNOUTH CISOLID  CO3--                       LBMOL/HR
        0.0            0.0           0.0
679     51  PRESSURE         KILNOUTH CISOLID                              PSIA
        29.0075        29.0075         0.0
680     52  MASS ENTHALPY    KILNOUTH CISOLID                              BTU/LB
        -4547.7721     -4547.7721         0.0
681
682        T - SIGNIFIES COMPONENT IS A TRACE COMPONENT
683
684                             *** ITERATION HISTORY ***
685
686        TEAR STREAMS AND TEAR VARIABLES:
687
688        ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
           ATTRIBUT ELEMENT
689        ---------   ----------- ----  ---------      ---------------- -------- --------
           -------- -------
690             1     -0.4628E-08     2  KILNOUTH       TOTAL MOLEFLOW
               CISOLID
691
692     CONVERGENCE BLOCK:  CH2OHOT
693     ---------------------------
694        Tear Stream  :  HYDH2OH
695        Tolerance used:  0.100D-03
696        Trace molefrac:  0.100D-05
697        Trace substr-2:  0.100D-05
698
699        MAXIT =   30 WAIT =   2
700        METHOD: BROYDEN       STATUS: CONVERGED
701        TOTAL NUMBER OF ITERATIONS:   312
702        NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1
703
704                             *** FINAL VALUES ***
705
706     VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
        VALUE       PREV VALUE       ERR/TOL
707     ----  ---------------  -------- -------- -------- -------- -------- -----------
        ------------   ------------   ------------
708        1  TOTAL MOLEFLOW   HYDH2OH  MIXED                               LBMOL/HR
           1743.8851      1743.8851      2.8510-07
709        2  TOTAL MOLEFLOW   HYDH2OH  CISOLID                             LBMOL/HR
           0.0            0.0            0.0
710        3  MOLE-FLOW        HYDH2OH  MIXED    O2                         LBMOL/HR
           0.0            0.0            0.0
711        4  MOLE-FLOW        HYDH2OH  MIXED    CO2                        LBMOL/HR
           0.0            0.0            0.0
712        5  MOLE-FLOW        HYDH2OH  MIXED    N2                         LBMOL/HR
           0.0            0.0            0.0
713        6  MOLE-FLOW        HYDH2OH  MIXED    WATER                      LBMOL/HR
           1743.8851      1743.8851      2.8510-07
714        7  MOLE-FLOW        HYDH2OH  MIXED    KOH                        LBMOL/HR
           0.0            0.0            0.0
715     FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                 04/15/2019  PAGE 12
716
717                                FLOWSHEET SECTION
718
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719    CONVERGENCE BLOCK:  CH2OHOT (CONTINUED)
720      8  MOLE-FLOW        HYDH2OH  MIXED    K2CO3                          LBMOL/HR
         0.0            0.0            0.0
721      9  MOLE-FLOW        HYDH2OH  MIXED    CACO3                          LBMOL/HR
         0.0            0.0            0.0
722     10  MOLE-FLOW        HYDH2OH  MIXED    CAO                            LBMOL/HR
         0.0            0.0            0.0
723     11  MOLE-FLOW        HYDH2OH  MIXED    CA(OH)2                        LBMOL/HR
         0.0            0.0            0.0
724     12  MOLE-FLOW        HYDH2OH  MIXED    CA++                           LBMOL/HR
         0.0            0.0            0.0
725     13  MOLE-FLOW        HYDH2OH  MIXED    H3O+                           LBMOL/HR
         1.9438-05      1.9438-05      2.8510-07
726     14  MOLE-FLOW        HYDH2OH  MIXED    CAOH+                          LBMOL/HR
         0.0            0.0            0.0
727     15  MOLE-FLOW        HYDH2OH  MIXED    K+                             LBMOL/HR
         0.0            0.0            0.0
728     16  MOLE-FLOW        HYDH2OH  MIXED    KOH(S)                         LBMOL/HR
         0.0            0.0            0.0
729     17  MOLE-FLOW        HYDH2OH  MIXED    KOH*W(S)                       LBMOL/HR
         0.0            0.0            0.0
730     18  MOLE-FLOW        HYDH2OH  MIXED    KOH:2(S)                       LBMOL/HR
         0.0            0.0            0.0
731     19  MOLE-FLOW        HYDH2OH  MIXED    CACO3(S)                       LBMOL/HR
         0.0            0.0            0.0
732     20  MOLE-FLOW        HYDH2OH  MIXED    K2CO3(S)                       LBMOL/HR
         0.0            0.0            0.0
733     21  MOLE-FLOW        HYDH2OH  MIXED    KHCO3(S)                       LBMOL/HR
         0.0            0.0            0.0
734     22  MOLE-FLOW        HYDH2OH  MIXED    CAOH2(S)                       LBMOL/HR
         0.0            0.0            0.0
735     23  MOLE-FLOW        HYDH2OH  MIXED    HCO3-                          LBMOL/HR
         0.0            0.0            0.0
736     24  MOLE-FLOW        HYDH2OH  MIXED    OH-                            LBMOL/HR
         1.9438-05      1.9438-05      2.8510-07
737     25  MOLE-FLOW        HYDH2OH  MIXED    CO3--                          LBMOL/HR
         0.0            0.0            0.0
738     26  PRESSURE         HYDH2OH  MIXED                                   PSIA
         14.5038        14.5038         0.0
739     27  MASS ENTHALPY    HYDH2OH  MIXED                                   BTU/LB
         -6708.3745     -6708.3745     -3.5576-12
740     28  MOLE-FLOW        HYDH2OH  CISOLID  O2                             LBMOL/HR
         0.0            0.0            0.0
741     29  MOLE-FLOW        HYDH2OH  CISOLID  CO2                            LBMOL/HR
         0.0            0.0            0.0
742     30  MOLE-FLOW        HYDH2OH  CISOLID  N2                             LBMOL/HR
         0.0            0.0            0.0
743     31  MOLE-FLOW        HYDH2OH  CISOLID  WATER                          LBMOL/HR
         0.0            0.0            0.0
744     32  MOLE-FLOW        HYDH2OH  CISOLID  KOH                            LBMOL/HR
         0.0            0.0            0.0
745     33  MOLE-FLOW        HYDH2OH  CISOLID  K2CO3                          LBMOL/HR
         0.0            0.0            0.0
746     34  MOLE-FLOW        HYDH2OH  CISOLID  CACO3                          LBMOL/HR
         0.0            0.0            0.0
747     35  MOLE-FLOW        HYDH2OH  CISOLID  CAO                            LBMOL/HR
         0.0            0.0            0.0
748     36  MOLE-FLOW        HYDH2OH  CISOLID  CA(OH)2                        LBMOL/HR
         0.0            0.0            0.0
749     37  MOLE-FLOW        HYDH2OH  CISOLID  CA++                           LBMOL/HR
         0.0            0.0            0.0
750     38  MOLE-FLOW        HYDH2OH  CISOLID  H3O+                           LBMOL/HR
         0.0            0.0            0.0
751     39  MOLE-FLOW        HYDH2OH  CISOLID  CAOH+                          LBMOL/HR
         0.0            0.0            0.0
752     40  MOLE-FLOW        HYDH2OH  CISOLID  K+                             LBMOL/HR
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      0.0            0.0            0.0
753    41  MOLE-FLOW        HYDH2OH  CISOLID  KOH(S)                      LBMOL/HR
      0.0            0.0            0.0
754    42  MOLE-FLOW        HYDH2OH  CISOLID  KOH*W(S)                    LBMOL/HR
      0.0            0.0            0.0
755    43  MOLE-FLOW        HYDH2OH  CISOLID  KOH:2(S)                    LBMOL/HR
      0.0            0.0            0.0
756    44  MOLE-FLOW        HYDH2OH  CISOLID  CACO3(S)                    LBMOL/HR
      0.0            0.0            0.0
757    45  MOLE-FLOW        HYDH2OH  CISOLID  K2CO3(S)                    LBMOL/HR
      0.0            0.0            0.0
758    46  MOLE-FLOW        HYDH2OH  CISOLID  KHCO3(S)                    LBMOL/HR
      0.0            0.0            0.0
759    47  MOLE-FLOW        HYDH2OH  CISOLID  CAOH2(S)                    LBMOL/HR
      0.0            0.0            0.0
760    48  MOLE-FLOW        HYDH2OH  CISOLID  HCO3-                       LBMOL/HR
      0.0            0.0            0.0
761    49  MOLE-FLOW        HYDH2OH  CISOLID  OH-                         LBMOL/HR
      0.0            0.0            0.0
762    50  MOLE-FLOW        HYDH2OH  CISOLID  CO3--                       LBMOL/HR
      0.0            0.0            0.0
763    51  PRESSURE         HYDH2OH  CISOLID                              PSIA
     14.5038        MISSING      1.0000+06
764    52  MASS ENTHALPY    HYDH2OH  CISOLID                              BTU/LB
     MISSING        MISSING         0.0
765
766                              *** ITERATION HISTORY ***
767  FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 13
768
769                                 FLOWSHEET SECTION
770
771   CONVERGENCE BLOCK:  CH2OHOT (CONTINUED)
772
773       TEAR STREAMS AND TEAR VARIABLES:
774
775       ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
          ATTRIBUT ELEMENT
776       ---------   ----------- ----  ---------      ---------------- -------- --------
          -------- -------
777            1      0.1000E+07    51  HYDH2OH        PRESSURE
               CISOLID
778
779   CONVERGENCE BLOCK:  CKOHFEED
780   ----------------------------
781       Tear Stream  :  KOHSOLHP
782       Tolerance used:  0.200D-03
783       Trace molefrac:  0.200D-05
784       Trace substr-2:  0.200D-05
785
786       MAXIT =   30 WAIT =   2
787       METHOD: BROYDEN       STATUS: CONVERGED
788       TOTAL NUMBER OF ITERATIONS:     7
789
790                              *** FINAL VALUES ***
791
792   VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
      VALUE       PREV VALUE       ERR/TOL
793   ----  ---------------  -------- -------- -------- -------- -------- -----------
      ------------   ------------   ------------
794      1  TOTAL MOLEFLOW   KOHSOLHP MIXED                               LBMOL/HR
         1.8581+06      1.8581+06     -1.2889-02
795      2  TOTAL MOLEFLOW   KOHSOLHP CISOLID                             LBMOL/HR
         0.0            0.0            0.0
796      3  MOLE-FLOW        KOHSOLHP MIXED    O2                        LBMOL/HR
         1.6945         1.6944         0.2522
797      4  MOLE-FLOW        KOHSOLHP MIXED    CO2                       LBMOL/HR
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      5.7906-12      5.7909-12        -0.3280
798   5  MOLE-FLOW        KOHSOLHP MIXED    N2                          LBMOL/HR
      3.2571         3.2570          0.2134
799   6  MOLE-FLOW        KOHSOLHP MIXED    WATER                       LBMOL/HR
      1.2438+06      1.2439+06     -1.8351-02
800   7  MOLE-FLOW        KOHSOLHP MIXED    KOH                         LBMOL/HR
      0.0            0.0             0.0
801   8  MOLE-FLOW        KOHSOLHP MIXED    K2CO3                       LBMOL/HR
      0.0            0.0             0.0
802   9  MOLE-FLOW        KOHSOLHP MIXED    CACO3                       LBMOL/HR
      0.0            0.0             0.0
803  10  MOLE-FLOW        KOHSOLHP MIXED    CAO                         LBMOL/HR
      0.0            0.0             0.0
804  11  MOLE-FLOW        KOHSOLHP MIXED    CA(OH)2                     LBMOL/HR
      0.0            0.0             0.0
805  12  MOLE-FLOW        KOHSOLHP MIXED    CA++                        LBMOL/HR
      3.6857-05      3.6861-05        -0.4591
806  13  MOLE-FLOW        KOHSOLHP MIXED    H3O+                        LBMOL/HR
      3.3801-13      3.3801-13     -1.7696-02
807  14  MOLE-FLOW        KOHSOLHP MIXED    CAOH+                       LBMOL/HR
      1.9617-02      1.9618-02        -0.2631
808  15  MOLE-FLOW        KOHSOLHP MIXED    K+                          LBMOL/HR
      3.1021+05      3.1021+05     -1.0348-02
809  16  MOLE-FLOW        KOHSOLHP MIXED    KOH(S)                      LBMOL/HR
      0.0            0.0             0.0
810  17  MOLE-FLOW        KOHSOLHP MIXED    KOH*W(S)                    LBMOL/HR
      0.0            0.0             0.0
811  18  MOLE-FLOW        KOHSOLHP MIXED    KOH:2(S)                    LBMOL/HR
      0.0            0.0             0.0
812  19  MOLE-FLOW        KOHSOLHP MIXED    CACO3(S)                    LBMOL/HR
      0.0            0.0             0.0
813  20  MOLE-FLOW        KOHSOLHP MIXED    K2CO3(S)                    LBMOL/HR
      0.0            0.0             0.0
814  21  MOLE-FLOW        KOHSOLHP MIXED    KHCO3(S)                    LBMOL/HR
      0.0            0.0             0.0
815  22  MOLE-FLOW        KOHSOLHP MIXED    CAOH2(S)                    LBMOL/HR
      1.7596-03      1.7599-03        -0.9675
816  23  MOLE-FLOW        KOHSOLHP MIXED    HCO3-                       LBMOL/HR
      6.9036-02      6.9047-02        -0.8133
817  24  MOLE-FLOW        KOHSOLHP MIXED    OH-                         LBMOL/HR
      2.9788+05      2.9788+05      2.4772-02
818  25  MOLE-FLOW        KOHSOLHP MIXED    CO3--                       LBMOL/HR
      6165.8777      6166.9366        -0.8585
819  26  PRESSURE         KOHSOLHP MIXED                                PSIA
      29.0075        29.0075         0.0
820  27  MASS ENTHALPY    KOHSOLHP MIXED                                BTU/LB
      -5407.3900     -5407.3903      3.2366-04
821  28  MOLE-FLOW        KOHSOLHP CISOLID  O2                          LBMOL/HR
      0.0            0.0             0.0
822  29  MOLE-FLOW        KOHSOLHP CISOLID  CO2                         LBMOL/HR
      0.0            0.0             0.0
823  30  MOLE-FLOW        KOHSOLHP CISOLID  N2                          LBMOL/HR
      0.0            0.0             0.0
824  31  MOLE-FLOW        KOHSOLHP CISOLID  WATER                       LBMOL/HR
      0.0            0.0             0.0
825  32  MOLE-FLOW        KOHSOLHP CISOLID  KOH                         LBMOL/HR
      0.0            0.0             0.0
826 FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 14
827
828                                FLOWSHEET SECTION
829
830   CONVERGENCE BLOCK:  CKOHFEED (CONTINUED)
831   33  MOLE-FLOW        KOHSOLHP CISOLID  K2CO3                       LBMOL/HR
      0.0            0.0             0.0
832   34  MOLE-FLOW        KOHSOLHP CISOLID  CACO3                       LBMOL/HR
      0.0            0.0             0.0
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 35  MOLE-FLOW        KOHSOLHP CISOLID  CAO                          LBMOL/HR
 0.0            0.0            0.0
 36  MOLE-FLOW        KOHSOLHP CISOLID  CA(OH)2                      LBMOL/HR
 0.0            0.0            0.0
 37  MOLE-FLOW        KOHSOLHP CISOLID  CA++                         LBMOL/HR
 0.0            0.0            0.0
 38  MOLE-FLOW        KOHSOLHP CISOLID  H3O+                         LBMOL/HR
 0.0            0.0            0.0
 39  MOLE-FLOW        KOHSOLHP CISOLID  CAOH+                        LBMOL/HR
 0.0            0.0            0.0
 40  MOLE-FLOW        KOHSOLHP CISOLID  K+                           LBMOL/HR
 0.0            0.0            0.0
 41  MOLE-FLOW        KOHSOLHP CISOLID  KOH(S)                       LBMOL/HR
 0.0            0.0            0.0
 42  MOLE-FLOW        KOHSOLHP CISOLID  KOH*W(S)                     LBMOL/HR
 0.0            0.0            0.0
 43  MOLE-FLOW        KOHSOLHP CISOLID  KOH:2(S)                     LBMOL/HR
 0.0            0.0            0.0
 44  MOLE-FLOW        KOHSOLHP CISOLID  CACO3(S)                     LBMOL/HR
 0.0            0.0            0.0
 45  MOLE-FLOW        KOHSOLHP CISOLID  K2CO3(S)                     LBMOL/HR
 0.0            0.0            0.0
 46  MOLE-FLOW        KOHSOLHP CISOLID  KHCO3(S)                     LBMOL/HR
 0.0            0.0            0.0
 47  MOLE-FLOW        KOHSOLHP CISOLID  CAOH2(S)                     LBMOL/HR
 0.0            0.0            0.0
 48  MOLE-FLOW        KOHSOLHP CISOLID  HCO3-                        LBMOL/HR
 0.0            0.0            0.0
 49  MOLE-FLOW        KOHSOLHP CISOLID  OH-                          LBMOL/HR
 0.0            0.0            0.0
 50  MOLE-FLOW        KOHSOLHP CISOLID  CO3--                        LBMOL/HR
 0.0            0.0            0.0
 51  PRESSURE         KOHSOLHP CISOLID                               PSIA
 29.0075        29.0075         0.0
 52  MASS ENTHALPY    KOHSOLHP CISOLID                               BTU/LB
 MISSING        MISSING         0.0

                        *** ITERATION HISTORY ***

    TEAR STREAMS AND TEAR VARIABLES:

    ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
    ATTRIBUT ELEMENT
    ---------   ----------- ----  ---------      ---------------- -------- --------
    -------- -------
         1       560.9         6  KOHSOLHP       MOLE-FLOW        MIXED
         WATER
         2       28.46         6  KOHSOLHP       MOLE-FLOW        MIXED
         WATER
         3       9.589         6  KOHSOLHP       MOLE-FLOW        MIXED
         WATER
         4       9.686        25  KOHSOLHP       MOLE-FLOW        MIXED
         CO3--
         5      -1.773        25  KOHSOLHP       MOLE-FLOW        MIXED
         CO3--
         6      -9.594        25  KOHSOLHP       MOLE-FLOW        MIXED
         CO3--
         7     -0.9675        22  KOHSOLHP       MOLE-FLOW        MIXED
         CAOH2(S)

 CONVERGENCE BLOCK:  CPELLOUT
 ----------------------------
    Tear Stream  :  PELLTOUT
    Tolerance used:  0.500D-03
    Trace molefrac:  0.500D-05
    Trace substr-2:  0.500D-05
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MAXIT = 50 WAIT = 2
METHOD: BROYDEN STATUS: CONVERGED
TOTAL NUMBER OF ITERATIONS: 157
NUMBER OF ITERATIONS ON LAST OUTER LOOP: 6

FLOWSHEET SECTION

CONVERGENCE BLOCK: CPELLOUT (CONTINUED)

*** FINAL VALUES ***

VAR#	TEAR STREAM VAR	STREAM	SUBSTREA	COMPONEN	ATTRIBUT	ELEMENT	UNIT	VALUE	PREV VALUE	ERR/TOL
1	TOTAL MOLEFLOW	PELLTOUT	MIXED				LBMOL/HR	1.9354+06	1.9354+06	3.1426-03
2	TOTAL MOLEFLOW	PELLTOUT	CISOLID				LBMOL/HR	1585.3501	1585.3501	0.0
3	MOLE-FLOW	PELLTOUT	MIXED	O2			LBMOL/HR	1.7926	1.7927	-6.9233-02
4	MOLE-FLOW	PELLTOUT	MIXED	CO2			LBMOL/HR	3.5460-12	3.5460-12	6.8919-03
5	MOLE-FLOW	PELLTOUT	MIXED	N2			LBMOL/HR	3.4457	3.4458	-5.8887-02
6	MOLE-FLOW	PELLTOUT	MIXED	WATER			LBMOL/HR	1.3132+06	1.3132+06	3.3082-03
7	MOLE-FLOW	PELLTOUT	MIXED	KOH			LBMOL/HR	0.0	0.0	0.0
8	MOLE-FLOW	PELLTOUT	MIXED	K2CO3			LBMOL/HR	0.0	0.0	0.0
9	MOLE-FLOW	PELLTOUT	MIXED	CACO3			LBMOL/HR	0.0	0.0	0.0
10	MOLE-FLOW	PELLTOUT	MIXED	CAO			LBMOL/HR	0.0	0.0	0.0
11	MOLE-FLOW	PELLTOUT	MIXED	CA(OH)2			LBMOL/HR	0.0	0.0	0.0
12	MOLE-FLOW	PELLTOUT	MIXED	CA++			LBMOL/HR	4.5872-05	4.5872-05	1.5693-02
13	MOLE-FLOW	PELLTOUT	MIXED	H3O+			LBMOL/HR	2.6406-13	2.6406-13	1.5231-02
14	MOLE-FLOW	PELLTOUT	MIXED	CAOH+			LBMOL/HR	2.2626-02	2.2626-02	9.4575-03
15	MOLE-FLOW	PELLTOUT	MIXED	K+			LBMOL/HR	3.1170+05	3.1169+05	5.3803-04
16	MOLE-FLOW	PELLTOUT	MIXED	KOH(S)			LBMOL/HR	0.0	0.0	0.0
17	MOLE-FLOW	PELLTOUT	MIXED	KOH*W(S)			LBMOL/HR	0.0	0.0	0.0
18	MOLE-FLOW	PELLTOUT	MIXED	KOH:2(S)			LBMOL/HR	0.0	0.0	0.0
19	MOLE-FLOW	PELLTOUT	MIXED	CACO3(S)			LBMOL/HR	4034.2694	4033.4719	0.3954
20	MOLE-FLOW	PELLTOUT	MIXED	K2CO3(S)			LBMOL/HR	0.0	0.0	0.0
21	MOLE-FLOW	PELLTOUT	MIXED	KHCO3(S)			LBMOL/HR	0.0	0.0	0.0
22	MOLE-FLOW	PELLTOUT	MIXED	CAOH2(S)			LBMOL/HR	1316.5721	1316.6698	-0.1484
23	MOLE-FLOW	PELLTOUT	MIXED	HCO3-			LBMOL/HR	7.6092-02	7.6092-02	1.3993-03
24	MOLE-FLOW	PELLTOUT	MIXED	OH-			LBMOL/HR	2.9862+05	2.9862+05	5.8383-04
25	MOLE-FLOW	PELLTOUT	MIXED	CO3--			LBMOL/HR			

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      6536.7225      6536.7242     -5.1077-04
912   26  PRESSURE          PELLTOUT MIXED                                PSIA
      14.5038        14.5038         0.0
913   27  MASS ENTHALPY     PELLTOUT MIXED                                BTU/LB
      -5451.9893     -5451.9887     -2.0748-04
914   28  MOLE-FLOW         PELLTOUT CISOLID  O2                          LBMOL/HR
      0.0            0.0            0.0
915   29  MOLE-FLOW         PELLTOUT CISOLID  CO2                         LBMOL/HR
      0.0            0.0            0.0
916   30  MOLE-FLOW         PELLTOUT CISOLID  N2                          LBMOL/HR
      0.0            0.0            0.0
917   31  MOLE-FLOW         PELLTOUT CISOLID  WATER                       LBMOL/HR
      0.0            0.0            0.0
918   32  MOLE-FLOW         PELLTOUT CISOLID  KOH                         LBMOL/HR
      0.0            0.0            0.0
919   33  MOLE-FLOW         PELLTOUT CISOLID  K2CO3                       LBMOL/HR
      0.0            0.0            0.0
920   34  MOLE-FLOW         PELLTOUT CISOLID  CACO3                       LBMOL/HR
      0.0            0.0            0.0
921   35  MOLE-FLOW         PELLTOUT CISOLID  CAO                         LBMOL/HR
      0.0            0.0            0.0
922   36  MOLE-FLOW         PELLTOUT CISOLID  CA(OH)2                     LBMOL/HR
      0.0            0.0            0.0
923   37  MOLE-FLOW         PELLTOUT CISOLID  CA++                        LBMOL/HR
      0.0            0.0            0.0
924   38  MOLE-FLOW         PELLTOUT CISOLID  H3O+                        LBMOL/HR
      0.0            0.0            0.0
925   39  MOLE-FLOW         PELLTOUT CISOLID  CAOH+                       LBMOL/HR
      0.0            0.0            0.0
926   40  MOLE-FLOW         PELLTOUT CISOLID  K+                          LBMOL/HR
      0.0            0.0            0.0
927   41  MOLE-FLOW         PELLTOUT CISOLID  KOH(S)                      LBMOL/HR
      0.0            0.0       -2000.0000     T
928   42  MOLE-FLOW         PELLTOUT CISOLID  KOH*W(S)                    LBMOL/HR
      0.0            0.0            0.0
929   43  MOLE-FLOW         PELLTOUT CISOLID  KOH:2(S)                    LBMOL/HR
      0.0            0.0            0.0
930   44  MOLE-FLOW         PELLTOUT CISOLID  CACO3(S)                    LBMOL/HR
      1585.3501      1585.3501        0.0
931   45  MOLE-FLOW         PELLTOUT CISOLID  K2CO3(S)                    LBMOL/HR
      0.0            0.0       -2000.0000     T
932   46  MOLE-FLOW         PELLTOUT CISOLID  KHCO3(S)                    LBMOL/HR
      0.0            0.0            0.0
933   47  MOLE-FLOW         PELLTOUT CISOLID  CAOH2(S)                    LBMOL/HR
      0.0            0.0       -2000.0000     T
934   48  MOLE-FLOW         PELLTOUT CISOLID  HCO3-                       LBMOL/HR
      0.0            0.0            0.0
935   49  MOLE-FLOW         PELLTOUT CISOLID  OH-                         LBMOL/HR
      0.0            0.0            0.0
936   50  MOLE-FLOW         PELLTOUT CISOLID  CO3--                       LBMOL/HR
      0.0            0.0            0.0
937   51  PRESSURE          PELLTOUT CISOLID                              PSIA
      14.5038        14.5038         0.0
938 FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 16
939
940                              FLOWSHEET SECTION
941
942  CONVERGENCE BLOCK:  CPELLOUT (CONTINUED)
943   52  MASS ENTHALPY     PELLTOUT CISOLID                              BTU/LB
      -5186.2343     -5186.2343         0.0
944
945      T - SIGNIFIES COMPONENT IS A TRACE COMPONENT
946
947                           *** ITERATION HISTORY ***
948
949      TEAR STREAMS AND TEAR VARIABLES:
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950
951        ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
           ATTRIBUT ELEMENT
952        ---------   ----------- ----  ---------      ---------------- -------- --------
           -------- -------
953             1      -5.840        19  PELLTOUT       MOLE-FLOW        MIXED
                CACO3(S)
954             2       8.351        19  PELLTOUT       MOLE-FLOW        MIXED
                CACO3(S)
955             3       8.384        22  PELLTOUT       MOLE-FLOW        MIXED
                CAOH2(S)
956             4      -1.825        22  PELLTOUT       MOLE-FLOW        MIXED
                CAOH2(S)
957             5      -2.079        22  PELLTOUT       MOLE-FLOW        MIXED
                CAOH2(S)
958             6      0.3954        19  PELLTOUT       MOLE-FLOW        MIXED
                CACO3(S)
959
960    CONVERGENCE BLOCK:  $OLVER01
961    ----------------------------
962        SPECS: CAHYDHX
963        MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
964                    MAX-STEP=       100.    % OF RANGE
965                    XTOL=       1.000000E-08
966        THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
967        METHOD: SECANT        STATUS: CONVERGED
968        TOTAL NUMBER OF ITERATIONS:   325
969        NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1
970
971                              *** FINAL VALUES ***
972
973
974    VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                              UNIT
       VALUE       PREV VALUE       ERR/TOL
975    ----  ---------------- -------------------------                       -----------
       ------------   ------------   ------------
976       1  WATER MASSFLOW   CAHYDCWI.MIXED.WATER.MASSFLOW                   LB/HR
          1.1450+05      1.1450+05     -5.0002-03
977
978                              *** ITERATION HISTORY ***
979
980        DESIGN-SPEC ID:
           CAHYDHX

981        ITERATED:  WATER MASSFLOW IN STREAM CAHYDCWI SUBSTREAM MIXED
982
983        ITERATION  VARIABLE         ERROR          ERR/TOL
984        ---------  --------         -----          -------
985             1     0.1145E+06      -0.5000E-05    -0.5000E-02
986
987    CONVERGENCE BLOCK:  $OLVER02
988    ----------------------------
989        SPECS: CAOHXCW
990    FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 17
991
992                                  FLOWSHEET SECTION
993
994    CONVERGENCE BLOCK:  $OLVER02 (CONTINUED)
995        MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
996                    MAX-STEP=       100.    % OF RANGE
997                    XTOL=       1.000000E-08
998        THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
999        METHOD: SECANT        STATUS: CONVERGED
1000       TOTAL NUMBER OF ITERATIONS:   329
1001       NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1
1002
```

```
                          *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                              UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- ------------------------                      -----------
------------   ------------   ------------
   1  WATER MASSFLOW   CAOHXCWI.MIXED.WATER.MASSFLOW                LB/HR
   8.8872+05      8.8872+05        -0.9838

                          *** ITERATION HISTORY ***

     DESIGN-SPEC ID:
     CAOHXCW

     ITERATED:  WATER MASSFLOW IN STREAM CAOHXCWI SUBSTREAM MIXED

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1     0.8887E+06      -0.9838E-03    -0.9838

 CONVERGENCE BLOCK:  $OLVER03
 ----------------------------
     SPECS: CARECH2O
     MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
                 MAX-STEP=       100.    % OF RANGE
                 XTOL=       1.000000E-08
     THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
     METHOD: SECANT        STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:   318
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                          *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                              UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- ------------------------                      -----------
------------   ------------   ------------
   1  TOTAL MASSFLOW   CARECWTR.MIXED.TOTAL.MASSFLOW                LB/HR
   3158.4201      3158.4201     -1.1902-02

                          *** ITERATION HISTORY ***
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 18

                             FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER03 (CONTINUED)

     DESIGN-SPEC ID:
     CARECH2O

     ITERATED:  TOTAL MASSFLOW IN STREAM CARECWTR SUBSTREAM MIXED

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1      3158.          -0.1190E-04    -0.1190E-01

 COMPUTATIONAL SEQUENCE
 ----------------------

 SEQUENCE USED WAS:
    INPUTS SATFLASH HUMIDITY
    CKOHFEED
    |  CPELLOUT CACO3SPL KCACENT KOHSPLIT KOHH2O KOHMIX SCRUBBER WETCAKEC
    |  |  CACO3WC
```

```
      |  |  CDECOUT CAOCO2SP SCREWHX CO3HTRS SCREWHTR CO3FLASH KILNHT KILN
      |  |  (RETURN CDECOUT)
      |  |  $OLVER02 *CAOHX
      |  |  (RETURN $OLVER02)
      |  |  CAOWATER
      |  |  CH2OHOT HYDRATOR CAOH2SPL H2OHYD1 H2OHYD2
      |  |  (RETURN CH2OHOT)
      |  |  $OLVER03 CAOH2REC
      |  |  (RETURN $OLVER03)
      |  |  CAPUMP
      |  |  $OLVER01 CAHYDRHX
      |  |  (RETURN $OLVER01)
      |  |  CAPELREC RECSPL KOHPUMP AIRSEP CAOHSPEC CAOH2MIX PELLMIX
      |  |  *PELLETRX
      |  (RETURN CPELLOUT)
      (RETURN CKOHFEED)

 OVERALL FLOWSHEET BALANCE
 -------------------------

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       O2                        0.110869E+07    0.110869E+07    0.162670E-10
       CO2                        2113.80         1585.35         0.250000
       N2                        0.417370E+07    0.417370E+07    0.118897E-10
       WATER                      194166.         194695.        -0.271834E-02
       KOH                        0.00000         0.00000         0.00000
       K2CO3                      0.00000         0.00000         0.00000
       CACO3                      0.00000         0.00000         0.00000
       CAO                        0.00000         0.00000         0.00000
       CA(OH)2                    0.00000         0.00000         0.00000
       CA++                      0.229362E-06    0.927415E-03   -0.999753
       H3O+                      0.132074E-03    0.257819E-03   -0.487727
       CAOH+                     0.113128E-03    0.172490E-02   -0.934414
       K+                         1558.47         17143.2        -0.909091
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 19

                                FLOWSHEET SECTION

 OVERALL FLOWSHEET BALANCE (CONTINUED)

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (LBMOL/HR)
       KOH(S)                     15584.3         0.00000         1.00000
       KOH*W(S)                   0.00000         0.00000         0.00000
       KOH:2(S)                   0.00000         0.00000         0.00000
       CACO3(S)                   4047.12         4249.47        -0.476190E-01
       K2CO3(S)                   0.00000         0.00000         0.00000
       KHCO3(S)                   0.00000         0.00000         0.00000
       CAOH2(S)                   1650.50         1447.44         0.123028
       HCO3-                     0.380485E-03    0.422685E-02   -0.909984
       OH-                        1493.10         16425.5        -0.909099
       CO3--                      32.6858         358.840        -0.908913
    TOTAL BALANCE
       MOLE(LBMOL/HR)            0.550304E+07    0.551830E+07   -0.276519E-02
       MASS(LB/HR   )            0.157478E+09    0.157478E+09    0.712751E-07
       ENTHALPY(BTU/HR  )       -0.278286E+11   -0.292774E+11    0.494840E-01

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             93028.1      LB/HR
    PRODUCT STREAMS CO2E          69771.1      LB/HR
    NET STREAMS CO2E PRODUCTION  -23257.0      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION        -23257.0      LB/HR
```

PHYSICAL PROPERTIES SECTION

COMPONENTS

ID	TYPE	ALIAS	NAME
O2	C	O2	OXYGEN
CO2	C	CO2	CARBON-DIOXIDE
N2	C	N2	NITROGEN
WATER	C	H2O	WATER
KOH	C	KOH	POTASSIUM-HYDROXIDE
K2CO3	C	K2CO3	POTASSIUM-CARBONATE
CACO3	C	CACO3	CALCIUM-CARBONATE-CALCITE
CAO	C	CAO	CALCIUM-OXIDE
CA(OH)2	C	CA(OH)2	CALCIUM-HYDROXIDE
CA++	C	CA+2	CA++
H3O+	C	H3O+	H3O+
CAOH+	C	CAOH+	CAOH+
K+	C	K+	K+
KOH(S)	C	KOH	POTASSIUM-HYDROXIDE
KOH*W(S)	C	KOH*W	KOH*H2O
KOH:2(S)	C	KOH*2W	KOH*2H2O
CACO3(S)	C	CACO3	CALCIUM-CARBONATE-CALCITE
K2CO3(S)	C	K2CO3	POTASSIUM-CARBONATE
KHCO3(S)	C	KHCO3	POTASSIUM-BICARBONATE
CAOH2(S)	C	CA(OH)2	CALCIUM-HYDROXIDE
HCO3-	C	HCO3-	HCO3-
OH-	C	OH-	OH-
CO3--	C	CO3-2	CO3--

LISTID	SUPERCRITICAL COMPONENT LIST
GLOBAL	CO2 O2 N2

U-O-S BLOCK SECTION

BLOCK: AIRSEP MODEL: FLASH2

INLET STREAM:	SCRUBOUT
OUTLET VAPOR STREAM:	AIRVENT
OUTLET LIQUID STREAM:	LIQOUT
PROPERTY OPTION SET:	ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID:	GLOBAL
CHEMISTRY ID:	GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.726310E+07	0.726310E+07	0.00000
MASS(LB/HR)	0.194729E+09	0.194729E+09	0.157101E-11
ENTHALPY(BTU/HR)	-0.231169E+12	-0.231169E+12	-0.284469E-05

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.135793E-04	LB/HR
PRODUCT STREAMS CO2E	0.135833E-04	LB/HR
NET STREAMS CO2E PRODUCTION	0.402790E-08	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.402790E-08	LB/HR

*** INPUT DATA ***

TWO PHASE PQ FLASH		
PRESSURE DROP	PSI	0.0
SPECIFIED HEAT DUTY	BTU/HR	0.0
MAXIMUM NO. ITERATIONS		30

CONVERGENCE TOLERANCE 0.0025000

*** RESULTS ***

OUTLET TEMPERATURE C 25.003
OUTLET PRESSURE PSIA 14.504
VAPOR FRACTION 0.73641

U-O-S BLOCK SECTION

BLOCK: AIRSEP MODEL: FLASH2 (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
O2	0.15268	0.93210E-06	0.20733	0.22243E+06
CO2	0.42491E-13	0.19665E-17	0.57717E-13	29350.
N2	0.57477	0.17917E-05	0.78050	0.43562E+06
WATER	0.18890	0.68266	0.12172E-01	0.17830E-01
CA++	0.61059E-11	0.23165E-10	0.0000	0.0000
H3O+	0.0000	0.14335E-18	0.0000	0.0000
CAOH+	0.29430E-08	0.11165E-07	0.0000	0.0000
K+	0.42284E-01	0.16042	0.0000	0.0000
HCO3-	0.10851E-07	0.41167E-07	0.0000	0.0000
OH-	0.40440E-01	0.15342	0.0000	0.0000
CO3--	0.92201E-03	0.34979E-02	0.0000	0.0000

BLOCK: CACO3SPL MODEL: SSPLIT

INLET STREAM: PELLTOUT
OUTLET STREAMS: PELPRODO CACO3O
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.193700E+07	0.193701E+07	-0.708027E-05
MASS(LB/HR)	0.419755E+08	0.419755E+08	0.177498E-15
ENTHALPY(BTU/HR)	-0.228808E+12	-0.228808E+12	0.204683E-05

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

FRACTION OF FLOW

SUBSTRM=	STRM=	FRAC=
MIXED	PELPRODO	1.00000
CISOLID	CACO3O	1.00000

U-O-S BLOCK SECTION

BLOCK: CACO3SPL MODEL: SSPLIT (CONTINUED)

*** RESULTS ***

STRM= PELPRODO SUBSTRM= MIXED SPLIT FRACT= 1.00000

```
                              CISOLID                         0.0

 STRM= CACO3O     SUBSTRM= MIXED    SPLIT FRACT=          0.0
                              CISOLID                         1.00000

 BLOCK:  CACO3WC  MODEL: MIXER
 ------------------------------
   INLET STREAMS:         CACO3O      WETCAKEW
   OUTLET STREAM:         CO3TOHT
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            2048.91         2048.91          0.00000
       MASS(LB/HR   )            167024.         167024.          0.00000
       ENTHALPY(BTU/HR  )     -0.879916E+09   -0.879916E+09    0.459270E-13

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 24

                               U-O-S BLOCK SECTION

 BLOCK:  CAHYDRHX MODEL: HEATX
 ------------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             CAOH2WHP
   OUTLET STREAM:            CAHYDC
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
   COLD SIDE:
   ----------
   INLET STREAM:             CAHYDCWI
   OUTLET STREAM:            CAHYDCWO
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            8188.06         8188.11       -0.607712E-05
       MASS(LB/HR   )            231965.         231965.       -0.250933E-15
       ENTHALPY(BTU/HR  )     -0.146215E+10   -0.146215E+10   -0.148598E-07

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR
```

```
                          ***  INPUT DATA  ***

    FLASH SPECS FOR HOT SIDE:
    TWO    PHASE      FLASH
    MAXIMUM NO. ITERATIONS                                  30
    CONVERGENCE TOLERANCE                                    0.000100000

    FLASH SPECS FOR COLD SIDE:
    TWO    PHASE      FLASH
    MAXIMUM NO. ITERATIONS                                  30
    CONVERGENCE TOLERANCE                                    0.000100000
FF  ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 25

                               U-O-S BLOCK SECTION

 BLOCK:  CAHYDRHX MODEL: HEATX (CONTINUED)

    FLOW DIRECTION AND SPECIFICATION:
      COUNTERCURRENT   HEAT EXCHANGER
      SPECIFIED HOT OUTLET TEMP
      SPECIFIED VALUE               C                       25.0000
      LMTD CORRECTION FACTOR                                   1.00000

    PRESSURE SPECIFICATION:
      HOT  SIDE PRESSURE DROP       PSI                        0.0000
      COLD SIDE PRESSURE DROP       PSI                        0.0000

    HEAT TRANSFER COEFFICIENT SPECIFICATION:
      HOT LIQUID    COLD LIQUID     BTU/HR-SQFT-R            149.6937
      HOT 2-PHASE   COLD LIQUID     BTU/HR-SQFT-R            149.6937
      HOT VAPOR     COLD LIQUID     BTU/HR-SQFT-R            149.6937
      HOT LIQUID    COLD 2-PHASE    BTU/HR-SQFT-R            149.6937
      HOT 2-PHASE   COLD 2-PHASE    BTU/HR-SQFT-R            149.6937
      HOT VAPOR     COLD 2-PHASE    BTU/HR-SQFT-R            149.6937
      HOT LIQUID    COLD VAPOR      BTU/HR-SQFT-R            149.6937
      HOT 2-PHASE   COLD VAPOR      BTU/HR-SQFT-R            149.6937
      HOT VAPOR     COLD VAPOR      BTU/HR-SQFT-R            149.6937

                          ***  OVERALL RESULTS  ***

    STREAMS:
                    ---------------------------------------
                    |                                     |
    CAOH2WHP  ----->|               HOT                   |-----> CAHYDC
    T=  5.5162D+01  |                                     |       T=  2.5000D+01
    P=  2.9008D+01  |                                     |       P=  2.9008D+01
    V=  0.0000D+00  |                                     |       V=  0.0000D+00
                    |                                     |
    CAHYDCWO  <-----|               COLD                  |<----- CAHYDCWI
    T=  1.5000D+01  |                                     |       T=  5.0000D+00
    P=  1.4504D+01  |                                     |       P=  1.4504D+01
    V=  0.0000D+00  |                                     |       V=  0.0000D+00
                    ---------------------------------------

    DUTY AND AREA:
      CALCULATED HEAT DUTY          BTU/HR            2063675.6764
      CALCULATED (REQUIRED) AREA    SQFT                  264.8411
      ACTUAL EXCHANGER AREA         SQFT                  264.8411
      PER CENT OVER-DESIGN                                  0.0000

    HEAT TRANSFER COEFFICIENT:
      AVERAGE COEFFICIENT (DIRTY)   BTU/HR-SQFT-R           149.6937
      UA (DIRTY)                    BTU/HR-R            39645.0318

    LOG-MEAN TEMPERATURE DIFFERENCE:
```

```
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)              C                        28.9188
     NUMBER OF SHELLS IN SERIES                              2

   PRESSURE DROP:
     HOTSIDE, TOTAL                PSI                       0.0000
     COLDSIDE, TOTAL               PSI                       0.0000
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                              U-O-S BLOCK SECTION

 BLOCK:  CAHYDRHX MODEL: HEATX (CONTINUED)

                         ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                    HOT
         ------------------------------------------------------------
         |                                                          |
 HOT IN  |                          LIQ                             | HOT OUT
 ------> |                                                          |------>
   55.2  |                                                          |   25.0
         |                                                          |
 COLDOUT |                          LIQ                             | COLDIN
 <------ |                                                          |<------
   15.0  |                                                          |    5.0
         |                                                          |
         ------------------------------------------------------------
                                    COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              BTU/HR          SQFT        C         BTU/HR-SQFT-R   BTU/HR-R
     1    2063675.676       264.8411      28.9188   149.6937       39645.0318
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 27

                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU CAHYDRHX TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

 ---------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    14.5038 !    15.0000 !     0.0    !
 !  9.8270+04 !    14.5038 !    14.5230 !     0.0    !
 !  1.9654+05 !    14.5038 !    14.0461 !     0.0    !
 !  2.9481+05 !    14.5038 !    13.5693 !     0.0    !
 !  3.9308+05 !    14.5038 !    13.0925 !     0.0    !
 !------------+------------+------------+------------!
 !  4.9135+05 !    14.5038 !    12.6158 !     0.0    !
 !  5.8962+05 !    14.5038 !    12.1392 !     0.0    !
 !  6.8789+05 !    14.5038 !    11.6626 !     0.0    !
 !  7.8616+05 !    14.5038 !    11.1861 !     0.0    !
```

8.8443+05	14.5038	10.7097	0.0
9.8270+05	14.5038	10.2334	0.0
1.0810+06	14.5038	9.7571	0.0
1.1792+06	14.5038	9.2810	0.0
1.2775+06	14.5038	8.8049	0.0
1.3758+06	14.5038	8.3289	0.0
1.4741+06	14.5038	7.8530	0.0
1.5723+06	14.5038	7.3773	0.0
1.6706+06	14.5038	6.9016	0.0
1.7689+06	14.5038	6.4261	0.0
1.8671+06	14.5038	5.9506	0.0
1.9654+06	14.5038	5.4753	0.0
2.0637+06	14.5038	5.0001	0.0

U-O-S BLOCK SECTION

HEATX HOT-TQCUR CAHYDRHX TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	29.0075	55.1616	0.0
9.8270+04	29.0075	53.7486	0.0
1.9654+05	29.0075	52.3333	0.0
2.9481+05	29.0075	50.9159	0.0
3.9308+05	29.0075	49.4963	0.0
4.9135+05	29.0075	48.0745	0.0
5.8962+05	29.0075	46.6505	0.0
6.8789+05	29.0075	45.2241	0.0
7.8616+05	29.0075	43.7970	0.0
8.8443+05	29.0075	42.3679	0.0
9.8270+05	29.0075	40.9367	0.0
1.0810+06	29.0075	39.5035	0.0
1.1792+06	29.0075	38.0572	0.0
1.2775+06	29.0075	36.6166	0.0
1.3758+06	29.0075	35.1736	0.0
1.4741+06	29.0075	33.7280	0.0
1.5723+06	29.0075	32.2798	0.0
1.6706+06	29.0075	30.8291	0.0
1.7689+06	29.0075	29.3758	0.0
1.8671+06	29.0075	27.9199	0.0
1.9654+06	29.0075	26.4613	0.0
2.0637+06	29.0075	25.0000	0.0

BLOCK: CAOCO2SP MODEL: FLASH2

```
 ------------------------------
   INLET STREAM:          KILNOUTH
   OUTLET VAPOR STREAM:   CO2HOT
   OUTLET LIQUID STREAM:  CAOOUT
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 29

                              U-O-S BLOCK SECTION

 BLOCK:  CAOCO2SP MODEL: FLASH2 (CONTINUED)

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            3170.70         3170.70         0.00000
       MASS(LB/HR   )            158673.         158673.        0.128394E-14
       ENTHALPY(BTU/HR  )     -0.645285E+09   -0.645285E+09   -0.129317E-14

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             69770.9      LB/HR
    PRODUCT STREAMS CO2E          69770.9      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE C                                  850.000
   PRESSURE DROP         PSI                                 0.0
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

                            ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                   850.00
   OUTLET PRESSURE       PSIA                                29.008
   HEAT DUTY             BTU/HR                             0.81250E-07
   VAPOR FRACTION                                            1.0000



   V-L PHASE EQUILIBRIUM :

      COMP             F(I)           X(I)           Y(I)           K(I)
      CO2              1.0000         1.0000         1.0000         64944.

 BLOCK:  CAOH2MIX MODEL: MIXER
 ------------------------------
   INLET STREAMS:         CAOH2FED    CARECIN     CAHYDC
   OUTLET STREAM:         CAOH2IN
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 30

                              U-O-S BLOCK SECTION

 BLOCK:  CAOH2MIX MODEL: MIXER (CONTINUED)

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            16430.1         16429.9        0.126682E-04
       MASS(LB/HR   )            815985.         815985.        0.285337E-15
       ENTHALPY(BTU/HR  )     -0.441671E+10   -0.441671E+10   -0.538285E-06
```

```
                        ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.00000      LB/HR
     PRODUCT STREAMS CO2E          0.00000      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***
     TWO    PHASE      FLASH
     MAXIMUM NO. ITERATIONS                                    30
     CONVERGENCE TOLERANCE                                      0.000100000
     OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

  BLOCK:  CAOH2REC MODEL: MIXER
  ------------------------------
     INLET STREAMS:         CAOH2WRM    CARECWTR
     OUTLET STREAM:         CAOH2WLP
     PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
     HENRY-COMPS ID:        GLOBAL
     CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
     TOTAL BALANCE
        MOLE(LBMOL/HR)            1832.08         1832.16       -0.442689E-04
        MASS(LB/HR   )            117461.         117461.         0.00000
        ENTHALPY(BTU/HR  )      -0.676505E+09   -0.676505E+09   -0.172357E-08

                        ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.00000      LB/HR
     PRODUCT STREAMS CO2E          0.00000      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 31

                               U-O-S BLOCK SECTION

  BLOCK:  CAOH2REC MODEL: MIXER (CONTINUED)

                             ***  INPUT DATA  ***
     TWO    PHASE      FLASH
     MAXIMUM NO. ITERATIONS                                    30
     CONVERGENCE TOLERANCE                                      0.000100000
     OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

  BLOCK:  CAOH2SPL MODEL: FSPLIT
  ------------------------------
     INLET STREAM:          HYDPRODS
     OUTLET STREAMS:        CAOH2PRG    CAOH2H
     PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
     HENRY-COMPS ID:        GLOBAL
     CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
     TOTAL BALANCE
        MOLE(LBMOL/HR)            1743.93         1743.93        0.130380E-15
        MASS(LB/HR   )            120319.         120319.        0.120945E-15
        ENTHALPY(BTU/HR  )      -0.687207E+09   -0.687207E+09   -0.173469E-15

                        ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.00000      LB/HR
     PRODUCT STREAMS CO2E          0.00000      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
```

```
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***

  FRACTION OF FLOW                 STRM=CAOH2PRG FRAC=         0.050000

                            ***  RESULTS  ***

  STREAM= CAOH2PRG       SPLIT=          0.050000    KEY=  0    STREAM-ORDER=   1
          CAOH2H                         0.95000           0                    2
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 32

                              U-O-S BLOCK SECTION

 BLOCK:  CAOHX    MODEL: HEATX
 ------------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             CAOOUT
   OUTLET STREAM:            CAOHOT
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
   COLD SIDE:
   ----------
   INLET STREAM:             CAOHXCWI
   OUTLET STREAM:            CAOHXCWO
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES


     **********************************************************************
     *                                                                    *
     *     ZERO FLOW SHELLSIDE MIXED SUBSTREAM: U-OPTION SET TO "CONSTANT" *
     *                                                                    *
     **********************************************************************


                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            50916.5         50916.5        0.285799E-15
       MASS(LB/HR   )            977617.         977617.        0.357242E-15
       ENTHALPY(BTU/HR  )     -0.645856E+10   -0.645856E+10    0.385504E-09

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 33

                              U-O-S BLOCK SECTION

 BLOCK:  CAOHX    MODEL: HEATX (CONTINUED)
```

```
  FLASH SPECS FOR COLD SIDE:
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                30
  CONVERGENCE TOLERANCE                                  0.000100000

  FLOW DIRECTION AND SPECIFICATION:
    MULTIPLE TUBE PASS SHELL AND TUBE HEAT EXCHANGER
    NUMBER OF SHELLS IN SERIES:                          1.00
    SPECIFIED HOT OUTLET TEMP
    SPECIFIED VALUE               C                     90.0000
    MINIMUM LMTD CORRECTION FACTOR:                      0.80000

  PRESSURE SPECIFICATION:
    HOT  SIDE PRESSURE DROP       PSI                    0.0000
    COLD SIDE PRESSURE DROP       PSI                    0.0000

  HEAT TRANSFER COEFFICIENT SPECIFICATION:
    OVERALL COEFFICIENT           BTU/HR-SQFT-R        149.6937

                      ***  OVERALL RESULTS  ***

  STREAMS:
                  ---------------------------------------
                  |                                     |
  CAOOUT    ----->|               HOT                   |-----> CAOHOT
  T=  8.5000D+02  |                                     |       T=  9.0000D+01
  P=  2.9008D+01  |                                     |       P=  2.9008D+01
  V=  0.0000D+00  |                                     |       V=  0.0000D+00
                  |                                     |
  CAOHXCWO  <-----|               COLD                  |<----- CAOHXCWI
  T=  4.8889D+01  |                                     |       T=  3.2220D+01
  P=  1.4504D+01  |                                     |       P=  1.4504D+01
  V=  0.0000D+00  |                                     |       V=  0.0000D+00
                  ---------------------------------------

  DUTY AND AREA:
    CALCULATED HEAT DUTY          BTU/HR          26610441.3837
    CALCULATED (REQUIRED) AREA    SQFT                363.4286
    ACTUAL EXCHANGER AREA         SQFT                363.4286
    PER CENT OVER-DESIGN                                0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)   BTU/HR-SQFT-R        149.6937
    UA (DIRTY)                    BTU/HR-R          54402.9608

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                              0.9612
    LMTD (CORRECTED)              C                   271.7422
    NUMBER OF SHELLS IN SERIES                           1

  PRESSURE DROP:
    HOTSIDE, TOTAL                PSI                   0.0000
    COLDSIDE, TOTAL               PSI                   0.0000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                04/15/2019  PAGE 34

                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU CAOHX    TQCURV INLET
 ------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

  ----------------------------------------------------
```

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	14.5038	48.8890	0.0
1.2672+06	14.5038	48.0955	0.0
2.5343+06	14.5038	47.3020	0.0
3.8015+06	14.5038	46.5085	0.0
5.0687+06	14.5038	45.7149	0.0
6.3358+06	14.5038	44.9213	0.0
7.6030+06	14.5038	44.1276	0.0
8.8701+06	14.5038	43.3339	0.0
1.0137+07	14.5038	42.5402	0.0
1.1404+07	14.5038	41.7464	0.0
1.2672+07	14.5038	40.9526	0.0
1.3939+07	14.5038	40.1588	0.0
1.5206+07	14.5038	39.3650	0.0
1.6473+07	14.5038	38.5712	0.0
1.7740+07	14.5038	37.7773	0.0
1.9007+07	14.5038	36.9834	0.0
2.0275+07	14.5038	36.1895	0.0
2.1542+07	14.5038	35.3956	0.0
2.2809+07	14.5038	34.6017	0.0
2.4076+07	14.5038	33.8078	0.0
2.5343+07	14.5038	33.0139	0.0
2.6610+07	14.5038	32.2200	0.0

U-O-S BLOCK SECTION

HEATX HOT-TQCUR CAOHX TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	29.0075	850.0000	0.0
1.2672+06	29.0075	815.7852	0.0
2.5343+06	29.0075	781.4503	0.0
3.8015+06	29.0075	746.9906	0.0
5.0687+06	29.0075	712.4009	0.0
6.3358+06	29.0075	677.6753	0.0
7.6030+06	29.0075	642.8072	0.0
8.8701+06	29.0075	607.7887	0.0
1.0137+07	29.0075	572.6109	0.0
1.1404+07	29.0075	537.2634	0.0

```
!  1.2672+07 !    29.0075 !   501.7339 !     0.0    !
!  1.3939+07 !    29.0075 !   466.0075 !     0.0    !
!  1.5206+07 !    29.0075 !   430.0665 !     0.0    !
!  1.6473+07 !    29.0075 !   393.8892 !     0.0    !
!  1.7740+07 !    29.0075 !   357.4484 !     0.0    !
!------------+------------+------------+------------!
!  1.9007+07 !    29.0075 !   320.7101 !     0.0    !
!  2.0275+07 !    29.0075 !   283.6300 !     0.0    !
!  2.1542+07 !    29.0075 !   246.1496 !     0.0    !
!  2.2809+07 !    29.0075 !   208.1894 !     0.0    !
!  2.4076+07 !    29.0075 !   169.6374 !     0.0    !
!------------+------------+------------+------------!
!  2.5343+07 !    29.0075 !   130.3275 !     0.0    !
!  2.6610+07 !    29.0075 !    90.0000 !     0.0    !
-----------------------------------------------------

BLOCK:  CAPUMP   MODEL: PUMP
-----------------------------
  INLET STREAM:          CAOH2WLP
  OUTLET STREAM:         CAOH2WHP
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 36

                              U-O-S BLOCK SECTION

BLOCK:  CAPUMP   MODEL: PUMP (CONTINUED)

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            1832.16         1832.16        0.328084E-07
      MASS(LB/HR   )            117461.         117461.       -0.123887E-15
      ENTHALPY(BTU/HR  )     -0.676505E+09   -0.676502E+09   -0.472320E-05

                       ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E             0.00000      LB/HR
   PRODUCT STREAMS CO2E          0.00000      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***
   PRESSURE CHANGE  PSI                                    14.5038
   PUMP EFFICIENCY                                          0.75000
   DRIVER EFFICIENCY                                        1.00000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                             30
   TOLERANCE                                                0.000100000

                           ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                          892.868
   PRESSURE CHANGE  PSI                                    14.5038
   NPSH AVAILABLE   FT-LBF/LB                              28.5273
   FLUID POWER  HP                                          0.94182
   BRAKE POWER  HP                                          1.25575
   ELECTRICITY  KW                                          0.93642
   PUMP EFFICIENCY USED                                     0.75000
   NET WORK REQUIRED  HP                                    1.25575
   HEAD DEVELOPED FT-LBF/LB                                15.8758

BLOCK:  CO3FLASH MODEL: FLASH2
```

```
  ------------------------------
    INLET STREAM:          CO3TOFLS
    OUTLET VAPOR STREAM:   CO3LIQO
    OUTLET LIQUID STREAM:  CO3HTDRY
    PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
    HENRY-COMPS ID:        GLOBAL
    CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 37

                              U-O-S BLOCK SECTION

 BLOCK:  CO3FLASH MODEL: FLASH2 (CONTINUED)

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            2048.91         2048.91         0.00000
       MASS(LB/HR   )            167024.         167024.         0.00000
       ENTHALPY(BTU/HR  )     -0.853184E+09   -0.853184E+09      0.00000

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
    TWO    PHASE  TP  FLASH
    SPECIFIED TEMPERATURE C                                  269.542
    PRESSURE DROP         PSI                                  0.0
    MAXIMUM NO. ITERATIONS                                    30
    CONVERGENCE TOLERANCE                                      0.00100000

                            ***  RESULTS  ***
    OUTLET TEMPERATURE    C                                    269.54
    OUTLET PRESSURE       PSIA                                 14.504
    HEAT DUTY             BTU/HR                            -0.95032E-07
    VAPOR FRACTION                                             1.0000



    V-L PHASE EQUILIBRIUM :

       COMP              F(I)           X(I)           Y(I)           K(I)
       WATER             1.0000         1.0000         1.0000         45.858
       H3O+              0.0000        0.55938E-07     0.0000         0.0000
       OH-               0.0000        0.55938E-07     0.0000         0.0000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 38

                              U-O-S BLOCK SECTION

 BLOCK:  H2OHYD1  MODEL: HEATX
 ------------------------------
    HOT SIDE:
    ---------
    INLET STREAM:             CAOH2H
    OUTLET STREAM:            CAOH2WRM
    PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
    HENRY-COMPS ID:        GLOBAL
    CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
    COLD SIDE:
    ----------
    INLET STREAM:             HYDH2OC
    OUTLET STREAM:            HYDH2OW
    PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
```

```
1983      HENRY-COMPS ID:        GLOBAL
1984      CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
1985
1986                          ***  MASS AND ENERGY BALANCE  ***
1987                                       IN              OUT        RELATIVE DIFF.
1988       TOTAL BALANCE
1989          MOLE(LBMOL/HR)            3400.62         3400.64       -0.636885E-05
1990          MASS(LB/HR   )            145720.         145720.         0.00000
1991          ENTHALPY(BTU/HR  )     -0.867275E+09   -0.867275E+09   -0.171972E-08
1992
1993                          ***  CO2 EQUIVALENT SUMMARY ***
1994       FEED STREAMS CO2E             0.00000      LB/HR
1995       PRODUCT STREAMS CO2E          0.00000      LB/HR
1996       NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
1997       UTILITIES CO2E PRODUCTION     0.00000      LB/HR
1998       TOTAL CO2E PRODUCTION         0.00000      LB/HR
1999
2000                               ***  INPUT DATA  ***
2001
2002      FLASH SPECS FOR HOT SIDE:
2003      TWO    PHASE      FLASH
2004      MAXIMUM NO. ITERATIONS                                    30
2005      CONVERGENCE TOLERANCE                                      0.000100000
2006
2007      FLASH SPECS FOR COLD SIDE:
2008      TWO    PHASE      FLASH
2009      MAXIMUM NO. ITERATIONS                                    30
2010      CONVERGENCE TOLERANCE                                      0.000100000
2011  FF  ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/15/2019  PAGE 39
2012
2013                                  U-O-S BLOCK SECTION
2014
2015    BLOCK:  H2OHYD1  MODEL: HEATX (CONTINUED)
2016
2017      FLOW DIRECTION AND SPECIFICATION:
2018        MULTIPLE TUBE PASS SHELL AND TUBE HEAT EXCHANGER
2019        NUMBER OF SHELLS IN SERIES:                              1.00
2020        SPECIFIED COLD APPROACH TEMP
2021        SPECIFIED VALUE                C                        27.7800
2022        TEMPERATURE TOLERANCE          C                         0.01000
2023        MINIMUM LMTD CORRECTION FACTOR:                          0.80000
2024
2025      PRESSURE SPECIFICATION:
2026        HOT  SIDE PRESSURE DROP        PSI                       0.0000
2027        COLD SIDE PRESSURE DROP        PSI                       0.0000
2028
2029      HEAT TRANSFER COEFFICIENT SPECIFICATION:
2030        HOT LIQUID    COLD LIQUID      BTU/HR-SQFT-R           149.6937
2031        HOT 2-PHASE   COLD LIQUID      BTU/HR-SQFT-R           149.6937
2032        HOT VAPOR     COLD LIQUID      BTU/HR-SQFT-R           149.6937
2033        HOT LIQUID    COLD 2-PHASE     BTU/HR-SQFT-R           149.6937
2034        HOT 2-PHASE   COLD 2-PHASE     BTU/HR-SQFT-R           149.6937
2035        HOT VAPOR     COLD 2-PHASE     BTU/HR-SQFT-R           149.6937
2036        HOT LIQUID    COLD VAPOR       BTU/HR-SQFT-R           149.6937
2037        HOT 2-PHASE   COLD VAPOR       BTU/HR-SQFT-R           149.6937
2038        HOT VAPOR     COLD VAPOR       BTU/HR-SQFT-R           149.6937
2039
2040                               ***  OVERALL RESULTS  ***
2041
2042      STREAMS:
2043                      ----------------------------------------
2044                      |                                      |
2045      CAOH2H    ----->|                HOT                   |-----> CAOH2WRM
2046      T=  9.0000D+01  |                                      |       T=  5.7781D+01
2047      P=  1.4504D+01  |                                      |       P=  1.4504D+01
2048      V=  0.0000D+00  |                                      |       V=  0.0000D+00
```

```
                    |                                      |
  HYDH2OW   <-------|                COLD                  |<------- HYDH2OC
  T=  6.2220D+01    |                                      |         T=  2.5000D+01
  P=  1.4504D+01    |                                      |         P=  1.4504D+01
  V=  0.0000D+00    |                                      |         V=  0.0000D+00
                    ----------------------------------------

  DUTY AND AREA:
    CALCULATED HEAT DUTY           BTU/HR             2101149.2900
    CALCULATED (REQUIRED) AREA     SQFT                   273.8255
    ACTUAL EXCHANGER AREA          SQFT                   273.8255
    PER CENT OVER-DESIGN                                    0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R          149.6937
    UA (DIRTY)                     BTU/HR-R             40989.9446

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                                  0.9426
    LMTD (CORRECTED)               C                       28.4778
    NUMBER OF SHELLS IN SERIES                              2

  PRESSURE DROP:
    HOTSIDE, TOTAL                 PSI                      0.0000
    COLDSIDE, TOTAL                PSI                      0.0000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 40

                              U-O-S BLOCK SECTION

 BLOCK:  H2OHYD1  MODEL: HEATX (CONTINUED)

                         ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                                  HOT
          ------------------------------------------------------------
          |                                                          |
 HOT IN   |                          LIQ                             | HOT OUT
 ------>  |                                                          |------>
   90.0   |                                                          |   57.8
          |                                                          |
 COLDOUT  |                          LIQ                             | COLDIN
 <------  |                                                          |<------
   62.2   |                                                          |   25.0
          |                                                          |
          ------------------------------------------------------------
                                  COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
             BTU/HR          SQFT        C         BTU/HR-SQFT-R   BTU/HR-R
    1    2101149.290       273.8255      28.4778   149.6937       40989.9446
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 41

                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU H2OHYD1  TQCURV INLET
 ------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
```

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	14.5038	62.2200	0.0
1.0005+05	14.5038	60.4497	0.0
2.0011+05	14.5038	58.6791	0.0
3.0016+05	14.5038	56.9081	0.0
4.0022+05	14.5038	55.1369	0.0
5.0027+05	14.5038	53.3653	0.0
6.0033+05	14.5038	51.5936	0.0
7.0038+05	14.5038	49.8215	0.0
8.0044+05	14.5038	48.0493	0.0
9.0049+05	14.5038	46.2768	0.0
1.0005+06	14.5038	44.5042	0.0
1.1006+06	14.5038	42.7313	0.0
1.2007+06	14.5038	40.9584	0.0
1.3007+06	14.5038	39.1853	0.0
1.4008+06	14.5038	37.4121	0.0
1.5008+06	14.5038	35.6389	0.0
1.6009+06	14.5038	33.8656	0.0
1.7009+06	14.5038	32.0923	0.0
1.8010+06	14.5038	30.3191	0.0
1.9010+06	14.5038	28.5459	0.0
2.0011+06	14.5038	26.7729	0.0
2.1011+06	14.5038	25.0000	0.0

U-O-S BLOCK SECTION

HEATX HOT-TQCUR H2OHYD1 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	14.5038	90.0000	0.0
1.0005+05	14.5038	88.4890	0.0
2.0011+05	14.5038	86.9759	0.0
3.0016+05	14.5038	85.4605	0.0
4.0022+05	14.5038	83.9430	0.0
5.0027+05	14.5038	82.4233	0.0
6.0033+05	14.5038	80.9013	0.0
7.0038+05	14.5038	79.3770	0.0
8.0044+05	14.5038	77.8504	0.0
9.0049+05	14.5038	76.3215	0.0

1.0005+06	14.5038	74.7903	0.0
1.1006+06	14.5038	73.2571	0.0
1.2007+06	14.5038	71.7220	0.0
1.3007+06	14.5038	70.1847	0.0
1.4008+06	14.5038	68.6451	0.0
1.5008+06	14.5038	67.1033	0.0
1.6009+06	14.5038	65.5592	0.0
1.7009+06	14.5038	64.0025	0.0
1.8010+06	14.5038	62.4512	0.0
1.9010+06	14.5038	60.8973	0.0
2.0011+06	14.5038	59.3407	0.0
2.1011+06	14.5038	57.7814	0.0

BLOCK: H2OHYD2 MODEL: HEATER

INLET STREAM: HYDH2OW
OUTLET STREAM: HYDH2OH
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

U-O-S BLOCK SECTION

BLOCK: H2OHYD2 MODEL: HEATER (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	1743.89	1743.89	0.285100E-10
MASS(LB/HR)	31416.6	31416.6	0.285104E-10
ENTHALPY(BTU/HR)	-0.212328E+09	-0.210754E+09	-0.741034E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	C	90.0000
PRESSURE DROP	PSI	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	90.000
OUTLET PRESSURE	PSIA	14.504
HEAT DUTY	BTU/HR	0.15734E+07
OUTLET VAPOR FRACTION		0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	1.0000	1.0000	1.0000	0.70327
H3O+	0.58807E-08	0.11146E-07	0.0000	0.0000

```
      OH-              0.58807E-08    0.11146E-07     0.0000         0.0000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 44

                              U-O-S BLOCK SECTION

 BLOCK:  HYDRATOR MODEL: RSTOIC
 ------------------------------
   INLET STREAMS:         CAOHOT      HYDH2OH
   OUTLET STREAM:         HYDPRODS
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                      ***  MASS AND ENERGY BALANCE  ***
                             IN          OUT       GENERATION   RELATIVE DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)          3329.24       1743.93      -1585.35     -0.140040E-04
   MASS(LB/HR   )          120319.       120319.                     0.00000
   ENTHALPY(BTU/HR  )   -0.641672E+09 -0.687207E+09                 0.662609E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     WATER     -1.00    CAOH2(S)   1.00
     SUBSTREAM CISOLID :
     CAO       -1.00


   REACTION CONVERSION SPECS: NUMBER=    1
     REACTION #   1:
     SUBSTREAM:CISOLID  KEY COMP:CAO      CONV FRAC:  1.000




   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE C                                    90.0000
   SPECIFIED PRESSURE    PSIA                                 14.5038
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE                                       0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES            NO
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 45

                              U-O-S BLOCK SECTION

 BLOCK:  HYDRATOR MODEL: RSTOIC (CONTINUED)

                            ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                      90.000
   OUTLET PRESSURE       PSIA                                   14.504
   HEAT DUTY             BTU/HR                              -0.45535E+08
   VAPOR FRACTION                                             0.0000



   REACTION EXTENTS:
```

```
      REACTION          REACTION
      NUMBER            EXTENT
                        LBMOL/HR
      1                  1585.4

  V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)           K(I)
      WATER             1.0000        0.99953         1.0000        0.70330
      CA++              0.0000        0.11663E-03     0.0000         0.0000
      H3O+             0.12261E-06    0.59239E-12     0.0000         0.0000
      CAOH+             0.0000        0.60696E-04     0.0000         0.0000
      OH-              0.12261E-06    0.29395E-03     0.0000         0.0000

 BLOCK:  KCACENT  MODEL: CFUGE
 ------------------------------
   INLET STREAM:          PELPRODO
   OUTLET STREAMS:        KOHREC      CAPRCOUT
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
      MOLE(LBMOL/HR)           0.193542E+07    0.193542E+07    0.365305E-07
      MASS(LB/HR   )           0.418169E+08    0.418169E+08     0.00000
      ENTHALPY(BTU/HR  )      -0.227986E+12   -0.227986E+12   -0.122116E-07
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 46

                              U-O-S BLOCK SECTION

 BLOCK:  KCACENT  MODEL: CFUGE (CONTINUED)

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
   CALCULATION METHOD                                  SOLIDS SEPARATOR
   CLASSIFICATION CHARACTERISTIC                       PARTICLE SIZE
   FLUID RECOVERY TO FLUID OUTLET                        0.99500
   SOLIDS RECOVERY TO SOLIDS OUTLET                      1.00000
   SEPARATION SHARPNESS                                  0.0
   FINES OFFSET                                          0.0

   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE CHANGE    C                      0.0
   SPECIFIED PRESSURE    PSIA                            14.5038
   MAXIMUM NO. ITERATIONS                                30
   CONVERGENCE TOLERANCE                                  0.0025000

                           ***  RESULTS  ***
   FLUID FRACTION TO FLUID OUTLET                       0.99500
   SOLIDS FRACTION TO SOLID OUTLET                      1.00000
   SOLIDS LOAD OF FLUID                                 0.0
   FLUID LOAD OF SOLIDS                                 0.41183
   HEAT DUTY  BTU/HR                                     2784.1

 BLOCK:  KILN     MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          KILNFEED
```

```
     OUTLET STREAM:          KILNOUTH
     PROPERTY OPTION SET:    ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
     HENRY-COMPS ID:         GLOBAL
     CHEMISTRY ID:           GLOBAL   - TRUE SPECIES

                          ***  MASS AND ENERGY BALANCE  ***
                                  IN          OUT       GENERATION   RELATIVE DIFF.
     TOTAL BALANCE
     MOLE(LBMOL/HR)          1585.35       3170.70       1585.35     -0.925214E-12
     MASS(LB/HR   )          158673.       158673.                   -0.926087E-12
     ENTHALPY(BTU/HR  )   -0.759713E+09 -0.645285E+09                -0.150619
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/15/2019  PAGE 47

                                U-O-S BLOCK SECTION

 BLOCK:  KILN     MODEL: RSTOIC (CONTINUED)

                          ***  CO2 EQUIVALENT SUMMARY ***
      FEED STREAMS CO2E             0.00000      LB/HR
      PRODUCT STREAMS CO2E          69770.9      LB/HR
      NET STREAMS CO2E PRODUCTION   69770.9      LB/HR
      UTILITIES CO2E PRODUCTION     0.00000      LB/HR
      TOTAL CO2E PRODUCTION         69770.9      LB/HR

                             ***  INPUT DATA  ***
     STOICHIOMETRY MATRIX:

      REACTION #   1:
        SUBSTREAM MIXED   :
        CO2         1.00
        SUBSTREAM CISOLID :
        CAO         1.00    CACO3(S)  -1.00


     REACTION CONVERSION SPECS: NUMBER=    1
       REACTION #   1:
       SUBSTREAM:CISOLID  KEY COMP:CACO3(S) CONV FRAC:  1.000




     TWO    PHASE  TP  FLASH
     SPECIFIED TEMPERATURE C                                  850.000
     SPECIFIED PRESSURE    PSIA                                29.0075
     MAXIMUM NO. ITERATIONS                                    30
     CONVERGENCE TOLERANCE                                      0.000100000
     SIMULTANEOUS REACTIONS
     GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO

                              ***  RESULTS  ***
     OUTLET TEMPERATURE    C                                    850.00
     OUTLET PRESSURE       PSIA                                 29.008
     HEAT DUTY             BTU/HR                              0.11443E+09
     VAPOR FRACTION                                             1.0000



     REACTION EXTENTS:

        REACTION          REACTION
        NUMBER            EXTENT
                          LBMOL/HR
        1                  1585.4

     V-L PHASE EQUILIBRIUM :
```

```
      COMP              F(I)           X(I)           Y(I)           K(I)
      CO2               1.0000         1.0000         1.0000         64944.
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 48

                              U-O-S BLOCK SECTION

 BLOCK:  KILNHT   MODEL: HEATER
 ------------------------------
   INLET STREAM:          CO3HTDRY
   OUTLET STREAM:         KILNFEED
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            1585.35         1585.35          0.00000
       MASS(LB/HR   )            158673.         158673.          0.00000
       ENTHALPY(BTU/HR  )     -0.806633E+09   -0.759713E+09   -0.581682E-01

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               C                       850.000
   PRESSURE DROP                       PSI                       0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000



                            ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                   850.00
   OUTLET PRESSURE       PSIA                                14.504
   HEAT DUTY             BTU/HR                             0.46920E+08
   OUTLET VAPOR FRACTION                                     0.0000


FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 49

                              U-O-S BLOCK SECTION

 BLOCK:  KOHMIX   MODEL: MIXER
 ------------------------------
   INLET STREAMS:         KOHFEED     KOHRECIN    SCRUBH2O
   OUTLET STREAM:         KOHSOLLP
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)         0.184253E+07    0.185812E+07   -0.838715E-02
       MASS(LB/HR   )         0.399735E+08    0.399735E+08    0.186388E-15
       ENTHALPY(BTU/HR  )    -0.216154E+12   -0.216154E+12   -0.342125E-07

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
```

```
      NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
      UTILITIES CO2E PRODUCTION     0.00000      LB/HR
      TOTAL CO2E PRODUCTION         0.00000      LB/HR

                            ***  INPUT DATA  ***
    TWO    PHASE      FLASH
    MAXIMUM NO. ITERATIONS                                    30
    CONVERGENCE TOLERANCE                                      0.000100000
    OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

  BLOCK:  KOHPUMP  MODEL: PUMP
  ------------------------------
    INLET STREAM:          KOHSOLLP
    OUTLET STREAM:         KOHSOLHP
    PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
    HENRY-COMPS ID:        GLOBAL
    CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/15/2019  PAGE 50

                               U-O-S BLOCK SECTION

  BLOCK:  KOHPUMP  MODEL: PUMP (CONTINUED)
     TOTAL BALANCE
        MOLE(LBMOL/HR)           0.185812E+07    0.185812E+07    0.436060E-12
        MASS(LB/HR   )           0.399735E+08    0.399735E+08   -0.372776E-15
        ENTHALPY(BTU/HR  )      -0.216154E+12   -0.216152E+12   -0.756273E-05

                        ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.00000      LB/HR
     PRODUCT STREAMS CO2E          0.00000      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                            ***  INPUT DATA  ***
     PRESSURE CHANGE  PSI                                    14.5038
     PUMP EFFICIENCY                                          0.75000
     DRIVER EFFICIENCY                                        1.00000

     FLASH SPECIFICATIONS:
     LIQUID PHASE CALCULATION
     NO FLASH PERFORMED
     MAXIMUM NUMBER OF ITERATIONS                             30
     TOLERANCE                                                0.000100000

                             ***  RESULTS  ***
     VOLUMETRIC FLOW RATE  CUFT/HR                      447,834.
     PRESSURE CHANGE  PSI                                    14.5038
     NPSH AVAILABLE   FT-LBF/LB                              -1.42409
     FLUID POWER  HP                                        472.384
     BRAKE POWER  HP                                        629.846
     ELECTRICITY  KW                                        469.676
     PUMP EFFICIENCY USED                                     0.75000
     NET WORK REQUIRED  HP                                  629.846
     HEAD DEVELOPED FT-LBF/LB                                23.3985
     NEGATIVE NPSH MAY BE DUE TO VAPOR IN THE FEED OR UNACCOUNTED SUCTION HEAD.

  BLOCK:  KOHSPLIT MODEL: FSPLIT
  ------------------------------
    INLET STREAM:          KOHREC
    OUTLET STREAMS:        KOHPURGE    KOHRECIN
    PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
    HENRY-COMPS ID:        GLOBAL
```

```
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                     ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           0.192042E+07    0.192042E+07     0.00000
      MASS(LB/HR   )           0.411087E+08    0.411087E+08     0.00000
      ENTHALPY(BTU/HR  )      -0.224206E+12   -0.224206E+12     0.00000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 51

                             U-O-S BLOCK SECTION

 BLOCK:  KOHSPLIT MODEL: FSPLIT (CONTINUED)

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

  FRACTION OF FLOW                STRM=KOHPURGE FRAC=         0.050000

                           ***  RESULTS  ***

  STREAM= KOHPURGE       SPLIT=          0.050000    KEY=  0    STREAM-ORDER=   1
          KOHRECIN                       0.95000           0                    2

 BLOCK:  PELLETRX MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          PELLFEED
   OUTLET STREAM:         PELLTOUT
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES


     ***********************************************************************
     *                                                                     *
     *     CONVERSION FRACTIONS OF ONE OR MORE COMPONENTS WERE MODIFIED    *
     *                                                                     *
     ***********************************************************************


                     ***  MASS AND ENERGY BALANCE  ***
                            IN          OUT       GENERATION   RELATIVE DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)        0.193228E+07  0.193700E+07   1585.35     -0.161615E-02
   MASS(LB/HR   )        0.419757E+08  0.419755E+08                0.277216E-05
   ENTHALPY(BTU/HR  )   -0.228798E+12 -0.228808E+12                0.457811E-04

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      LB/HR
    PRODUCT STREAMS CO2E          0.00000      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 52

                             U-O-S BLOCK SECTION

 BLOCK:  PELLETRX MODEL: RSTOIC (CONTINUED)

                          ***  INPUT DATA  ***
```

```
  STOICHIOMETRY MATRIX:

   REACTION #   1:
    SUBSTREAM MIXED   :
    CA++      -1.00    K+         2.00
    SUBSTREAM CISOLID :
    CACO3(S)   1.00    K2CO3(S)  -1.00

   REACTION #   2:
    SUBSTREAM MIXED   :
    KOH(S)     2.00    CAOH2(S)  -1.00
    SUBSTREAM CISOLID :
    CACO3(S)   1.00    K2CO3(S)  -1.00

   REACTION #   3:
    SUBSTREAM MIXED   :
    KOH(S)     2.00    K2CO3(S)  -1.00    CAOH2(S)  -1.00
    SUBSTREAM CISOLID :
    CACO3(S)   1.00

   REACTION #   4:
    SUBSTREAM MIXED   :
    CA++      -1.00    K+         2.00    K2CO3(S)  -1.00
    SUBSTREAM CISOLID :
    CACO3(S)   1.00


  REACTION CONVERSION SPECS: NUMBER=    4
    REACTION #   1:
    SUBSTREAM:CISOLID  KEY COMP:K2CO3(S) CONV FRAC:  1.000
    REACTION #   2:
    SUBSTREAM:CISOLID  KEY COMP:K2CO3(S) CONV FRAC:  1.000
    REACTION #   3:
    SUBSTREAM:MIXED    KEY COMP:K2CO3(S) CONV FRAC:  1.000
    REACTION #   4:
    SUBSTREAM:MIXED    KEY COMP:K2CO3(S) CONV FRAC:  1.000



  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE C                                  25.0000
  SPECIFIED PRESSURE    PSIA                               14.5038
  MAXIMUM NO. ITERATIONS                                   30
  CONVERGENCE TOLERANCE                                     0.000100000
  SERIES REACTIONS
  GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 53

                              U-O-S BLOCK SECTION

 BLOCK:  PELLETRX MODEL: RSTOIC (CONTINUED)

                           ***  RESULTS  ***
  OUTLET TEMPERATURE    C                                    25.000
  OUTLET PRESSURE       PSIA                                 14.504
  HEAT DUTY             BTU/HR                            -0.11133E+08
  VAPOR FRACTION                                            0.0000



  REACTION EXTENTS:

     REACTION          REACTION
     NUMBER            EXTENT
                       LBMOL/HR
```

```
        1                 0.48100E-04
        2                  1585.4
        3                  0.0000
        4                  0.0000

    V-L PHASE EQUILIBRIUM :

       COMP              F(I)           X(I)           Y(I)           K(I)
       O2               0.93182E-06    0.92877E-06    0.20735        0.22309E+06
       CO2               0.0000        0.18373E-17    0.54392E-13     29583.
       N2               0.17911E-05    0.17853E-05    0.78059        0.43692E+06
       WATER            0.68262        0.68039        0.12055E-01    0.17705E-01
       CA++              0.0000        0.23767E-10     0.0000         0.0000
       H3O+              0.0000        0.13681E-18     0.0000         0.0000
       CAOH+            0.12038E-07    0.11723E-07     0.0000         0.0000
       K+               0.16038        0.16149         0.0000         0.0000
       HCO3-            0.39636E-07    0.39425E-07     0.0000         0.0000
       OH-              0.15362        0.15472         0.0000         0.0000
       CO3--            0.33786E-02    0.33868E-02     0.0000         0.0000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 54

                              U-O-S BLOCK SECTION

 BLOCK:  PELLMIX  MODEL: MIXER
 ------------------------------
    INLET STREAMS:         LIQOUT      CAOH2IN
    OUTLET STREAM:         PELLFEED
    PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
    HENRY-COMPS ID:        GLOBAL
    CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
     TOTAL BALANCE
       MOLE(LBMOL/HR)           0.193205E+07    0.193228E+07   -0.117324E-03
       MASS(LB/HR   )           0.419757E+08    0.419757E+08     0.00000
       ENTHALPY(BTU/HR  )      -0.228797E+12   -0.228798E+12    0.482945E-06

                        ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.00000      LB/HR
     PRODUCT STREAMS CO2E          0.00000      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
    TWO    PHASE      FLASH
    MAXIMUM NO. ITERATIONS                                    30
    CONVERGENCE TOLERANCE                                      0.000100000
    OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  RECSPL   MODEL: FSPLIT
 ------------------------------
    INLET STREAM:          CAPRCIN
    OUTLET STREAMS:        CARECIN     CARECPRG
    PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
    HENRY-COMPS ID:        GLOBAL
    CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 55

                              U-O-S BLOCK SECTION

 BLOCK:  RECSPL   MODEL: FSPLIT (CONTINUED)
```

```
     TOTAL BALANCE
        MOLE(LBMOL/HR)            15000.4         15000.4         0.00000
        MASS(LB/HR   )            708187.         708187.         0.00000
        ENTHALPY(BTU/HR  )     -0.377983E+10   -0.377983E+10   -0.252306E-15

                        ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.00000      LB/HR
     PRODUCT STREAMS CO2E          0.00000      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***

  FRACTION OF FLOW                STRM=CARECPRG FRAC=         0.050000

                            ***  RESULTS  ***

  STREAM= CARECIN        SPLIT=          0.95000     KEY=  0    STREAM-ORDER=   2
          CARECPRG                       0.050000          0                    1

 BLOCK:  SATFLASH MODEL: FLASH2
 ------------------------------
   INLET STREAMS:         SATAIR      SATWATER
   OUTLET VAPOR STREAM:   SATVAPOR
   OUTLET LIQUID STREAM:  SATLIQUI
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                        ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
     TOTAL BALANCE
        MOLE(LBMOL/HR)            1231.39         1231.39        0.409795E-07
        MASS(LB/HR   )            22266.7         22266.7        0.963955E-14
        ENTHALPY(BTU/HR  )     -0.150473E+09   -0.150469E+09   -0.315281E-04

                        ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.134495      LB/HR
     PRODUCT STREAMS CO2E          0.132275      LB/HR
     NET STREAMS CO2E PRODUCTION -0.222082E-02   LB/HR
     UTILITIES CO2E PRODUCTION      0.00000      LB/HR
     TOTAL CO2E PRODUCTION       -0.222082E-02   LB/HR
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 56

                              U-O-S BLOCK SECTION

 BLOCK:  SATFLASH MODEL: FLASH2 (CONTINUED)

                           ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE C                                    25.0000
   PRESSURE DROP         PSI                                   0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE                                      0.000100000

                            ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                     25.000
   OUTLET PRESSURE       PSIA                                  14.504
   HEAT DUTY             BTU/HR                                4744.1
   VAPOR FRACTION                                             0.63960E-02



   V-L PHASE EQUILIBRIUM :
```

COMP	F(I)	X(I)	Y(I)	K(I)
O2	0.13017E-02	0.45971E-05	0.20280	44116.
CO2	0.24818E-05	0.21542E-06	0.34815E-03	1616.1
N2	0.49003E-02	0.88516E-05	0.76477	86399.
WATER	0.99380	0.99999	0.32077E-01	0.32077E-01
H3O+	0.17944E-08	0.41323E-07	0.0000	0.0000
HCO3-	0.0000	0.41242E-07	0.0000	0.0000
OH-	0.17944E-08	0.79105E-10	0.0000	0.0000
CO3--	0.0000	0.84272E-12	0.0000	0.0000

BLOCK: SCREWHTR MODEL: HEATER

INLET STREAM: CO3HXHTR
OUTLET STREAM: CO3TOFLS
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	2048.91	2048.91	0.00000
MASS(LB/HR)	167024.	167024.	0.00000
ENTHALPY(BTU/HR)	-0.853184E+09	-0.853184E+09	0.301801E-13

U-O-S BLOCK SECTION

BLOCK: SCREWHTR MODEL: HEATER (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	LB/HR
PRODUCT STREAMS CO2E	0.00000	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

ONE PHASE TP FLASH SPECIFIED PHASE IS		VAPOR
SPECIFIED TEMPERATURE	C	269.542
PRESSURE DROP	PSI	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	269.54
OUTLET PRESSURE	PSIA	14.504
HEAT DUTY	BTU/HR	-0.95032E-07

BLOCK: SCREWHX MODEL: HEATX

HOT SIDE:

INLET STREAM: CO2HOT
OUTLET STREAM: CO2PROD
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES
COLD SIDE:

```
   ----------
   INLET STREAM:             CO3TOHT
   OUTLET STREAM:            CO3HXHTR
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            3634.26         3634.26         0.00000
       MASS(LB/HR   )            236795.         236795.         0.00000
       ENTHALPY(BTU/HR  )     -0.112089E+10   -0.112089E+10    0.226473E-08
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 58

                              U-O-S BLOCK SECTION

 BLOCK:  SCREWHX  MODEL: HEATX (CONTINUED)

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             69770.9      LB/HR
    PRODUCT STREAMS CO2E          69770.9      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT APPROACH TEMP
     SPECIFIED VALUE               C                        27.7800
     TEMPERATURE TOLERANCE         C                         0.01000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP       PSI                       0.0000
     COLD SIDE PRESSURE DROP       PSI                       0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID     BTU/HR-SQFT-R           149.6937
     HOT 2-PHASE   COLD LIQUID     BTU/HR-SQFT-R           149.6937
     HOT VAPOR     COLD LIQUID     BTU/HR-SQFT-R           149.6937
     HOT LIQUID    COLD 2-PHASE    BTU/HR-SQFT-R           149.6937
     HOT 2-PHASE   COLD 2-PHASE    BTU/HR-SQFT-R           149.6937
     HOT VAPOR     COLD 2-PHASE    BTU/HR-SQFT-R           149.6937
     HOT LIQUID    COLD VAPOR      BTU/HR-SQFT-R           149.6937
     HOT 2-PHASE   COLD VAPOR      BTU/HR-SQFT-R           149.6937
     HOT VAPOR     COLD VAPOR      BTU/HR-SQFT-R           149.6937
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 59

                              U-O-S BLOCK SECTION

 BLOCK:  SCREWHX  MODEL: HEATX (CONTINUED)

                          ***  OVERALL RESULTS  ***
```

```
  STREAMS:
                  --------------------------------------
                  |                                    |
  CO2HOT    ----->|               HOT                  |-----> CO2PROD
  T=  8.5000D+02  |                                    |       T=  5.2781D+01
  P=  2.9008D+01  |                                    |       P=  2.9008D+01
  V=  1.0000D+00  |                                    |       V=  1.0000D+00
                  |                                    |
  CO3HXHTR  <-----|               COLD                 |<----- CO3TOHT
  T=  2.6954D+02  |                                    |       T=  2.5001D+01
  P=  1.4504D+01  |                                    |       P=  1.4504D+01
  V=  1.0000D+00  |                                    |       V=  0.0000D+00
                  --------------------------------------

  DUTY AND AREA:
    CALCULATED HEAT DUTY           BTU/HR            26732271.9887
    CALCULATED (REQUIRED) AREA     SQFT                   508.7144
    ACTUAL EXCHANGER AREA          SQFT                   508.7144
    PER CENT OVER-DESIGN                                    0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R          149.6937
    UA (DIRTY)                     BTU/HR-R             76151.3315

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                                  1.0000
    LMTD (CORRECTED)               C                      195.0230
    NUMBER OF SHELLS IN SERIES                               1

  PRESSURE DROP:
    HOTSIDE, TOTAL                 PSI                      0.0000
    COLDSIDE, TOTAL                PSI                      0.0000

                       ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                                 HOT
        -------------------------------------------------------------
        |                   |                   |                   |
 HOT IN |       VAP         |       VAP         |       VAP         | HOT OUT
 ------>|                   |                   |                   |------>
  850.0 |              496.2|              249.6|                   |   52.8
        |                   |                   |                   |
 COLDOUT|       VAP         |       BOIL        |       LIQ         | COLDIN
 <------|                   |                   |                   |<------
  269.5 |               99.6|               99.6|                   |   25.0
        |                   |                   |                   |
        -------------------------------------------------------------
                                 COLD
```


BLOCK: SCREWHX MODEL: HEATX (CONTINUED)

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY BTU/HR	AREA SQFT	LMTD C	AVERAGE U BTU/HR-SQFT-R	UA BTU/HR-R
1	12925144.418	99.3741	482.7101	149.6937	14875.6704
2	8140935.235	119.1396	253.5958	149.6937	17834.4496
3	5666189.900	290.2007	72.4631	149.6937	43441.2046

HEATX COLD-TQCU SCREWHX TQCURV INLET

```
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         PSI
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
```

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	14.5038	269.5417	1.0000
1.2730+06	14.5038	253.5778	1.0000
2.5459+06	14.5038	237.4830	1.0000
3.8189+06	14.5038	221.2477	1.0000
5.0919+06	14.5038	204.8606	1.0000
6.3648+06	14.5038	188.3084	1.0000
7.6378+06	14.5038	171.5751	1.0000
8.9108+06	14.5038	154.6416	1.0000
1.0184+07	14.5038	137.4845	1.0000
1.1457+07	14.5038	120.0747	1.0000
1.2730+07	14.5038	102.3755	1.0000
1.2925+07	14.5038	99.6290	DEW>1.0000
1.4003+07	14.5038	99.6290	0.8676
1.5276+07	14.5038	99.6290	0.7113
1.6549+07	14.5038	99.6290	0.5549
1.7822+07	14.5038	99.6290	0.3985
1.9094+07	14.5038	99.6290	0.2422
2.0367+07	14.5038	99.6290	8.5817-02
2.1066+07	14.5038	99.6290	BUB>0.0
2.1640+07	14.5038	92.3645	0.0
2.2913+07	14.5038	76.0604	0.0
2.4186+07	14.5038	59.4404	0.0
2.5459+07	14.5038	42.4472	0.0
2.6732+07	14.5038	25.0011	0.0

HEATX HOT-TQCUR SCREWHX TQCURV INLET

```
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         PSI
  PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
  HENRY-COMPS ID:        GLOBAL
  CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
```

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	

```
   !============!============!============!============!
   !     0.0    !    29.0075 !   850.0000 !     1.0000 !
   !  1.2730+06 !    29.0075 !   816.4791 !     1.0000 !
   !  2.5459+06 !    29.0075 !   782.7049 !     1.0000 !
   !  3.8189+06 !    29.0075 !   748.6702 !     1.0000 !
   !  5.0919+06 !    29.0075 !   714.3653 !     1.0000 !
   !------------+------------+------------+------------!
   !  6.3648+06 !    29.0075 !   679.7771 !     1.0000 !
   !  7.6378+06 !    29.0075 !   644.8891 !     1.0000 !
   !  8.9108+06 !    29.0075 !   609.6807 !     1.0000 !
   !  1.0184+07 !    29.0075 !   574.1267 !     1.0000 !
   !  1.1457+07 !    29.0075 !   538.1966 !     1.0000 !
   !------------+------------+------------+------------!
   !  1.2730+07 !    29.0075 !   501.8541 !     1.0000 !
   !  1.2925+07 !    29.0075 !   496.2337 !     1.0000 !
   !  1.4003+07 !    29.0075 !   465.0554 !     1.0000 !
   !  1.5276+07 !    29.0075 !   427.7486 !     1.0000 !
   !  1.6549+07 !    29.0075 !   389.8716 !     1.0000 !
   !------------+------------+------------+------------!
   !  1.7822+07 !    29.0075 !   351.3500 !     1.0000 !
   !  1.9094+07 !    29.0075 !   312.0941 !     1.0000 !
   !  2.0367+07 !    29.0075 !   271.9951 !     1.0000 !
   !  2.1066+07 !    29.0075 !   249.5823 !     1.0000 !
   !  2.1640+07 !    29.0075 !   230.9191 !     1.0000 !
   !------------+------------+------------+------------!
   !  2.2913+07 !    29.0075 !   188.7002 !     1.0000 !
   !  2.4186+07 !    29.0075 !   145.1291 !     1.0000 !
   !  2.5459+07 !    29.0075 !    99.9384 !     1.0000 !
   !  2.6732+07 !    29.0075 !    52.7810 !     1.0000 !
   ------------------------------------------------------

   BLOCK:  SCRUBBER MODEL: RSTOIC
   ------------------------------
     INLET STREAMS:         AIRIN       KOHSOLHP
     OUTLET STREAM:         SCRUBOUT
     PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
     HENRY-COMPS ID:        GLOBAL
     CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/15/2019  PAGE 63

                                U-O-S BLOCK SECTION

   BLOCK:  SCRUBBER MODEL: RSTOIC (CONTINUED)

                         ***  MASS AND ENERGY BALANCE  ***
                                  IN          OUT       GENERATION   RELATIVE DIFF.
     TOTAL BALANCE
     MOLE(LBMOL/HR)        0.726838E+07  0.726310E+07  -4756.05      0.722709E-04
     MASS(LB/HR   )        0.194729E+09  0.194729E+09                 -0.539928E-06
     ENTHALPY(BTU/HR  )   -0.229612E+12 -0.231169E+12                  0.673708E-02

                         ***  CO2 EQUIVALENT SUMMARY ***
      FEED STREAMS CO2E             93027.9      LB/HR
      PRODUCT STREAMS CO2E         0.135793E-04  LB/HR
      NET STREAMS CO2E PRODUCTION  -93027.9      LB/HR
      UTILITIES CO2E PRODUCTION     0.00000      LB/HR
      TOTAL CO2E PRODUCTION        -93027.9      LB/HR

                            ***  INPUT DATA  ***
     STOICHIOMETRY MATRIX:

      REACTION #   1:
       SUBSTREAM MIXED   :
       CO2       -1.00    WATER      1.00    K+        -2.00    OH-       -2.00
       SUBSTREAM CISOLID :
       K2CO3(S)   1.00
```

REACTION CONVERSION SPECS: NUMBER= 1
REACTION # 1:
SUBSTREAM:MIXED KEY COMP:CO2 CONV FRAC: 0.7500

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	C	25.0000
SPECIFIED PRESSURE	PSIA	14.5038
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000
SIMULTANEOUS REACTIONS		
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES		NO

U-O-S BLOCK SECTION

BLOCK: SCRUBBER MODEL: RSTOIC (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	C	25.000
OUTLET PRESSURE	PSIA	14.504
HEAT DUTY	BTU/HR	-0.15569E+10
VAPOR FRACTION		0.73641

REACTION EXTENTS:

REACTION NUMBER	REACTION EXTENT LBMOL/HR
1	1585.4

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
O2	0.15267	0.93215E-06	0.20733	0.22242E+06
CO2	0.72769E-04	0.19657E-17	0.57700E-13	29353.
N2	0.57473	0.17918E-05	0.78050	0.43561E+06
WATER	0.18882	0.68266	0.12169E-01	0.17826E-01
CA++	0.50754E-11	0.23165E-10	0.0000	0.0000
H3O+	0.0000	0.14331E-18	0.0000	0.0000
CAOH+	0.27014E-08	0.11165E-07	0.0000	0.0000
K+	0.42281E-01	0.16042	0.0000	0.0000
HCO3-	0.95078E-08	0.41167E-07	0.0000	0.0000
OH-	0.40582E-01	0.15342	0.0000	0.0000
CO3--	0.84917E-03	0.34979E-02	0.0000	0.0000

STREAM SECTION

AIRIN AIRVENT CACO3O CAHYDC CAHYDCWI

STREAM ID	AIRIN	AIRVENT	CACO3O	CAHYDC	CAHYDCWI
FROM :	----	AIRSEP	CACO3SPL	CAHYDRHX	----
TO :	SCRUBBER	----	CACO3WC	CAOH2MIX	CAHYDRHX
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	1.5476+08	1.5357+08	1.5867+05	1.1746+05	1.1450+05
BTU/HR	-1.3460+10	-6.7880+09	-8.2292+08	-6.7857+08	-7.8565+08
SUBSTREAM: MIXED					

PHASE:	VAPOR	VAPOR	MISSING	MIXED	LIQUID
COMPONENTS: LBMOL/HR					
O2	1.1087+06	1.1087+06	0.0	0.0	0.0
CO2	2113.8001	3.0864-07	0.0	0.0	0.0
N2	4.1737+06	4.1737+06	0.0	0.0	0.0
WATER	1.2576+05	6.5087+04	0.0	325.9272	6355.9021
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	8.4887-02	0.0
H3O+	0.0	0.0	0.0	2.6291-12	4.9489-06
CAOH+	0.0	0.0	0.0	2.6982-02	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	1505.9707	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.1968	4.9489-06
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	5.4103+06	5.3475+06	0.0	1832.2066	6355.9021
LB/HR	1.5476+08	1.5357+08	0.0	1.1746+05	1.1450+05
CUFT/HR	2.1470+09	2.1223+09	0.0	891.7432	1834.1206
STATE VARIABLES:					
TEMP C	25.0000	25.0033	MISSING	25.0000	5.0000
PRES PSIA	14.5038	14.5038	MISSING	29.0075	14.5038
VFRAC	1.0000	1.0000	MISSING	0.0	0.0
LFRAC	0.0	0.0	MISSING	0.1781	1.0000
SFRAC	0.0	0.0	MISSING	0.8219	0.0
ENTHALPY:					
BTU/LBMOL	-2487.8150	-1269.3753	MISSING	-3.7035+05	-1.2361+05
BTU/LB	-86.9744	-44.2013	MISSING	-5776.9256	-6861.3369
BTU/HR	-1.3460+10	-6.7880+09	MISSING	-6.7857+08	-7.8565+08
ENTROPY:					
BTU/LBMOL-R	0.9975	1.0310	MISSING	-64.6684	-40.2217
BTU/LB-R	3.4872-02	3.5901-02	MISSING	-1.0087	-2.2326

STREAM SECTION

AIRIN AIRVENT CACO3O CAHYDC CAHYDCWI (CONTINUED)

STREAM ID	AIRIN	AIRVENT	CACO3O	CAHYDC	CAHYDCWI
DENSITY:					
LBMOL/CUFT	2.5199-03	2.5197-03	MISSING	2.0546	3.4654
LB/CUFT	7.2079-02	7.2360-02	MISSING	131.7211	62.4296
AVG MW	28.6040	28.7181	MISSING	64.1092	18.0153
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0

CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	1585.3501	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	0.0	0.0	1585.3501	0.0	0.0
LB/HR	0.0	0.0	1.5867+05	0.0	0.0
CUFT/HR	0.0	0.0	937.9342	0.0	0.0
STATE VARIABLES:					
TEMP C	MISSING	MISSING	25.0013	MISSING	MISSING
PRES PSIA	14.5038	14.5038	14.5038	29.0075	14.5038
VFRAC	MISSING	MISSING	0.0	MISSING	MISSING
LFRAC	MISSING	MISSING	0.0	MISSING	MISSING
SFRAC	MISSING	MISSING	1.0000	MISSING	MISSING
ENTHALPY:					
BTU/LBMOL	MISSING	MISSING	-5.1908+05	MISSING	MISSING
BTU/LB	MISSING	MISSING	-5186.2338	MISSING	MISSING
BTU/HR	MISSING	MISSING	-8.2292+08	MISSING	MISSING
ENTROPY:					
BTU/LBMOL-R	MISSING	MISSING	-62.9081	MISSING	MISSING
BTU/LB-R	MISSING	MISSING	-0.6285	MISSING	MISSING
DENSITY:					
LBMOL/CUFT	MISSING	MISSING	1.6903	MISSING	MISSING
LB/CUFT	MISSING	MISSING	169.1731	MISSING	MISSING
AVG MW	MISSING	MISSING	100.0872	MISSING	MISSING

STREAM SECTION

CAHYDCWO CAOH2FED CAOH2H CAOH2IN CAOH2PRG

STREAM ID	CAHYDCWO	CAOH2FED	CAOH2H	CAOH2IN	CAOH2PRG
FROM :	CAHYDRHX	----	CAOH2SPL	CAOH2MIX	CAOH2SPL
TO :	----	CAOH2MIX	H2OHYD1	PELLMIX	----
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	1.1450+05	2.5745+04	1.1430+05	8.1598+05	6015.9444
BTU/HR	-7.8358+08	-1.4731+08	-6.5285+08	-4.4167+09	-3.4360+07
SUBSTREAM: MIXED					
PHASE:	LIQUID	SOLID	MIXED	MIXED	MIXED
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	8.5151-03	0.0
CO2	0.0	0.0	0.0	2.0428-14	0.0
N2	0.0	0.0	0.0	1.6368-02	0.0
WATER	6355.9021	0.0	150.6083	6563.6330	7.9268
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	1.7573-02	2.9011-07	9.2489-04
H3O+	7.6989-06	0.0	8.9260-11	1.7086-15	4.6979-12
CAOH+	0.0	0.0	9.1456-03	1.2705-04	4.8134-04
K+	0.0	0.0	0.0	1480.5511	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0

KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	3844.7486	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	347.4755	1506.0559	3091.4440	79.2661
HCO3-	0.0	0.0	0.0	3.7516-04	0.0
OH-	7.6989-06	0.0	4.4292-02	1418.4251	2.3311-03
CO3--	0.0	0.0	0.0	31.0629	0.0
TOTAL FLOW:					
LBMOL/HR	6355.9021	347.4755	1656.7351	1.6430+04	87.1966
LB/HR	1.1450+05	2.5745+04	1.1430+05	8.1598+05	6015.9444
CUFT/HR	1835.5988	183.9905	842.5045	6216.9461	44.3423
STATE VARIABLES:					
TEMP C	15.0000	25.0000	90.0000	25.4096	90.0000
PRES PSIA	14.5038	14.5038	14.5038	14.5038	14.5038
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	0.0	9.0950-02	0.5778	9.0950-02
SFRAC	0.0	1.0000	0.9091	0.4222	0.9091
ENTHALPY:					
BTU/LBMOL	-1.2328+05	-4.2394+05	-3.9406+05	-2.6882+05	-3.9406+05
BTU/LB	-6843.3139	-5721.7561	-5711.5472	-5412.7372	-5711.5472
BTU/HR	-7.8358+08	-1.4731+08	-6.5285+08	-4.4167+09	-3.4360+07
ENTROPY:					
BTU/LBMOL-R	-39.5846	-70.2374	-63.1645	-46.6141	-63.1645
BTU/LB-R	-2.1973	-0.9480	-0.9155	-0.9386	-0.9155

STREAM SECTION

CAHYDCWO CAOH2FED CAOH2H CAOH2IN CAOH2PR (CONTINUED)

STREAM ID	CAHYDCWO	CAOH2FED	CAOH2H	CAOH2IN	CAOH2PRG
DENSITY:					
LBMOL/CUFT	3.4626	1.8886	1.9664	2.6428	1.9664
LB/CUFT	62.3793	139.9278	135.6704	131.2517	135.6704
AVG MW	18.0153	74.0927	68.9929	49.6646	68.9929

STREAM SECTION

CAOH2WHP CAOH2WLP CAOH2WRM CAOHOT CAOHXCWI

STREAM ID	CAOH2WHP	CAOH2WLP	CAOH2WRM	CAOHOT	CAOHXCWI
FROM :	CAPUMP	CAOH2REC	H2OHYD1	CAOHX	----
TO :	CAHYDRHX	CAPUMP	CAOH2REC	HYDRATOR	CAOHX
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	1.1746+05	1.1746+05	1.1430+05	8.8902+04	8.8872+05
BTU/HR	-6.7650+08	-6.7651+08	-6.5495+08	-4.3092+08	-6.0543+09
SUBSTREAM: MIXED					
PHASE:	MIXED	MIXED	MIXED	MISSING	LIQUID
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	325.9272	325.9272	150.6083	0.0	4.9331+04
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	6.1656-02	6.1684-02	2.7571-02	0.0	0.0
H3O+	2.4799-11	2.4728-11	1.3616-11	0.0	1.1602-04

	CAOH+	2.3685-02	2.3690-02	1.0808-02	0.0	0.0
	K+	0.0	0.0	0.0	0.0	0.0
	KOH(S)	0.0	0.0	0.0	0.0	0.0
	KOH*W(S)	0.0	0.0	0.0	0.0	0.0
	KOH:2(S)	0.0	0.0	0.0	0.0	0.0
	CACO3(S)	0.0	0.0	0.0	0.0	0.0
	K2CO3(S)	0.0	0.0	0.0	0.0	0.0
	KHCO3(S)	0.0	0.0	0.0	0.0	0.0
	CAOH2(S)	1505.9972	1505.9972	1506.0442	0.0	0.0
	HCO3-	0.0	0.0	0.0	0.0	0.0
	OH-	0.1470	0.1471	6.5950-02	0.0	1.1602-04
	CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:						
	LBMOL/HR	1832.1568	1832.1569	1656.7568	0.0	4.9331+04
	LB/HR	1.1746+05	1.1746+05	1.1430+05	0.0	8.8872+05
	CUFT/HR	892.8660	892.8682	841.6184	0.0	1.4306+04
STATE VARIABLES:						
	TEMP C	55.1616	55.1188	57.7814	90.0000	32.2200
	PRES PSIA	29.0075	14.5038	14.5038	29.0075	14.5038
	VFRAC	0.0	0.0	0.0	MISSING	0.0
	LFRAC	0.1780	0.1780	9.0968-02	MISSING	1.0000
	SFRAC	0.8220	0.8220	0.9090	MISSING	0.0
ENTHALPY:						
	BTU/LBMOL	-3.6924+05	-3.6924+05	-3.9532+05	MISSING	-1.2273+05
	BTU/LB	-5759.3567	-5759.3839	-5729.9295	MISSING	-6812.3688
	BTU/HR	-6.7650+08	-6.7651+08	-6.5495+08	MISSING	-6.0543+09
ENTROPY:						
	BTU/LBMOL-R	-62.6714	-62.6741	-65.1948	MISSING	-38.5406
	BTU/LB-R	-0.9775	-0.9776	-0.9450	MISSING	-2.1393

STREAM SECTION

CAOH2WHP CAOH2WLP CAOH2WRM CAOHOT CAOHXC (CONTINUED)

STREAM ID	CAOH2WHP	CAOH2WLP	CAOH2WRM	CAOHOT	CAOHXCWI
DENSITY:					
LBMOL/CUFT	2.0520	2.0520	1.9685	MISSING	3.4482
LB/CUFT	131.5554	131.5551	135.8133	MISSING	62.1197
AVG MW	64.1110	64.1110	68.9920	MISSING	18.0153
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	1585.3501	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	1.5434-12	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0

CO3--	0.0	0.0	0.0	0.0	0.0	
TOTAL FLOW:						
LBMOL/HR	0.0	0.0	0.0	1585.3501	0.0	
LB/HR	0.0	0.0	0.0	8.8902+04	0.0	
CUFT/HR	0.0	0.0	0.0	425.7196	0.0	
STATE VARIABLES:						
TEMP C	MISSING	MISSING	MISSING	90.0000	MISSING	
PRES PSIA	29.0075	14.5038	14.5038	29.0075	14.5038	
VFRAC	MISSING	MISSING	MISSING	0.0	MISSING	
LFRAC	MISSING	MISSING	MISSING	0.0	MISSING	
SFRAC	MISSING	MISSING	MISSING	1.0000	MISSING	
ENTHALPY:						
BTU/LBMOL	MISSING	MISSING	MISSING	-2.7181+05	MISSING	
BTU/LB	MISSING	MISSING	MISSING	-4847.0944	MISSING	
BTU/HR	MISSING	MISSING	MISSING	-4.3092+08	MISSING	
ENTROPY:						
BTU/LBMOL-R	MISSING	MISSING	MISSING	-23.2509	MISSING	
BTU/LB-R	MISSING	MISSING	MISSING	-0.4146	MISSING	
DENSITY:						
LBMOL/CUFT	MISSING	MISSING	MISSING	3.7239	MISSING	
LB/CUFT	MISSING	MISSING	MISSING	208.8283	MISSING	
AVG MW	MISSING	MISSING	MISSING	56.0774	MISSING	

STREAM SECTION

CAOHXCWO CAOOUT CAPRCIN CAPRCOUT CARECIN

STREAM ID	CAOHXCWO	CAOOUT	CAPRCIN	CAPRCOUT	CARECIN
FROM :	CAOHX	CAOCO2SP	----	KCACENT	RECSPL
TO :	----	CAOHX	RECSPL	----	CAOH2MIX
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	8.8872+05	8.8902+04	7.0819+05	7.0819+05	6.7278+05
BTU/HR	-6.0276+09	-4.0431+08	-3.7798+09	-3.7798+09	-3.5908+09
SUBSTREAM: MIXED					
PHASE:	LIQUID	MISSING	MIXED	MIXED	MIXED
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	8.9633-03	8.9633-03	8.5151-03
CO2	0.0	0.0	1.7734-14	1.7734-14	1.6848-14
N2	0.0	0.0	1.7229-02	1.7229-02	1.6368-02
WATER	4.9331+04	0.0	6566.0061	6566.0061	6237.7058
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	2.2936-07	2.2936-07	2.1789-07
H3O+	1.9956-04	0.0	1.3205-15	1.3205-15	1.2544-15
CAOH+	0.0	0.0	1.1313-04	1.1313-04	1.0747-04
K+	0.0	0.0	1558.4748	1558.4748	1480.5511
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	4047.1158	4047.1158	3844.7600
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	1303.0259	1303.0259	1237.8746
HCO3-	0.0	0.0	3.8049-04	3.8049-04	3.6146-04
OH-	1.9956-04	0.0	1493.1031	1493.1031	1418.4479
CO3--	0.0	0.0	32.6858	32.6858	31.0515
TOTAL FLOW:					
LBMOL/HR	4.9331+04	0.0	1.5000+04	1.5000+04	1.4250+04
LB/HR	8.8872+05	0.0	7.0819+05	7.0819+05	6.7278+05
CUFT/HR	1.4400+04	0.0	5417.0951	5417.0951	5146.2403

STATE VARIABLES:						
TEMP	C	48.8890	MISSING	25.0013	25.0013	25.0013
PRES	PSIA	14.5038	29.0075	14.5038	14.5038	14.5038
VFRAC		0.0	MISSING	0.0	0.0	0.0
LFRAC		1.0000	MISSING	0.6433	0.6433	0.6433
SFRAC		0.0	MISSING	0.3567	0.3567	0.3567
ENTHALPY:						
BTU/LBMOL		-1.2219+05	MISSING	-2.5198+05	-2.5198+05	-2.5198+05
BTU/LB		-6782.4262	MISSING	-5337.3311	-5337.3311	-5337.3311
BTU/HR		-6.0276+09	MISSING	-3.7798+09	-3.7798+09	-3.5908+09
ENTROPY:						
BTU/LBMOL-R		-37.5851	MISSING	-43.7597	-43.7597	-43.7597
BTU/LB-R		-2.0863	MISSING	-0.9269	-0.9269	-0.9269

STREAM SECTION

CAOHXCWO CAOOUT CAPRCIN CAPRCOUT CARECIN (CONTINUED)

STREAM ID	CAOHXCWO	CAOOUT	CAPRCIN	CAPRCOUT	CARECIN
DENSITY:					
LBMOL/CUFT	3.4257	MISSING	2.7691	2.7691	2.7691
LB/CUFT	61.7150	MISSING	130.7319	130.7319	130.7319
AVG MW	18.0153	MISSING	47.2111	47.2111	47.2111
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	1585.3501	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	1.5434-12	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	0.0	1585.3501	0.0	0.0	0.0
LB/HR	0.0	8.8902+04	0.0	0.0	0.0
CUFT/HR	0.0	425.7196	0.0	0.0	0.0
STATE VARIABLES:					
TEMP C	MISSING	850.0000	MISSING	MISSING	MISSING
PRES PSIA	14.5038	29.0075	14.5038	14.5038	14.5038
VFRAC	MISSING	0.0	MISSING	MISSING	MISSING
LFRAC	MISSING	0.0	MISSING	MISSING	MISSING
SFRAC	MISSING	1.0000	MISSING	MISSING	MISSING
ENTHALPY:					
BTU/LBMOL	MISSING	-2.5503+05	MISSING	MISSING	MISSING
BTU/LB	MISSING	-4547.7721	MISSING	MISSING	MISSING
BTU/HR	MISSING	-4.0431+08	MISSING	MISSING	MISSING
ENTROPY:					

BTU/LBMOL-R	MISSING	-9.6073	MISSING	MISSING	MISSING
BTU/LB-R	MISSING	-0.1713	MISSING	MISSING	MISSING
DENSITY:						
LBMOL/CUFT	MISSING	3.7239	MISSING	MISSING	MISSING
LB/CUFT	MISSING	208.8283	MISSING	MISSING	MISSING
AVG MW	MISSING	56.0774	MISSING	MISSING	MISSING

STREAM SECTION

CARECPRG CARECWTR CO2HOT CO2PROD CO3HTDRY

STREAM ID	CARECPRG	CARECWTR	CO2HOT	CO2PROD	CO3HTDRY
FROM :	RECSPL	----	CAOCO2SP	SCREWHX	CO3FLASH
TO :	----	CAOH2REC	SCREWHX	----	KILNHT
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	3.5409+04	3158.4201	6.9771+04	6.9771+04	1.5867+05
BTU/HR	-1.8899+08	-2.1557+07	-2.4098+08	-2.6771+08	-8.0663+08
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	VAPOR	VAPOR	MISSING
COMPONENTS: LBMOL/HR					
O2	4.4816-04	0.0	0.0	0.0	0.0
CO2	8.8672-16	0.0	1585.3501	1585.3501	0.0
N2	8.6145-04	0.0	0.0	0.0	0.0
WATER	328.3003	175.3190	0.0	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	1.1468-08	0.0	0.0	0.0	0.0
H3O+	6.6023-17	3.1656-07	0.0	0.0	0.0
CAOH+	5.6564-06	0.0	0.0	0.0	0.0
K+	77.9237	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	202.3558	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	65.1513	0.0	0.0	0.0	0.0
HCO3-	1.9024-05	0.0	0.0	0.0	0.0
OH-	74.6552	3.1656-07	0.0	0.0	0.0
CO3--	1.6343	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	750.0219	175.3190	1585.3501	1585.3501	0.0
LB/HR	3.5409+04	3158.4201	6.9771+04	6.9771+04	0.0
CUFT/HR	270.8548	50.7368	1.1859+06	3.4148+05	0.0
STATE VARIABLES:					
TEMP C	25.0013	25.0000	850.0000	52.7810	MISSING
PRES PSIA	14.5038	14.5038	29.0075	29.0075	14.5038
VFRAC	0.0	0.0	1.0000	1.0000	MISSING
LFRAC	0.6433	1.0000	0.0	0.0	MISSING
SFRAC	0.3567	0.0	0.0	0.0	MISSING
ENTHALPY:					
BTU/LBMOL	-2.5198+05	-1.2296+05	-1.5200+05	-1.6886+05	MISSING
BTU/LB	-5337.3311	-6825.3373	-3453.8392	-3836.9826	MISSING
BTU/HR	-1.8899+08	-2.1557+07	-2.4098+08	-2.6771+08	MISSING
ENTROPY:					
BTU/LBMOL-R	-43.7597	-38.9708	14.1481	0.1283	MISSING
BTU/LB-R	-0.9269	-2.1632	0.3215	2.9158-03	MISSING

STREAM SECTION

CARECPRG CARECWTR CO2HOT CO2PROD CO3HTDR (CONTINUED)

STREAM ID	CARECPRG	CARECWTR	CO2HOT	CO2PROD	CO3HTDRY
DENSITY:					
LBMOL/CUFT	2.7691	3.4555	1.3368-03	4.6427-03	MISSING
LB/CUFT	130.7319	62.2511	5.8831-02	0.2043	MISSING
AVG MW	47.2111	18.0153	44.0098	44.0098	MISSING
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	1585.3501
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	0.0	0.0	0.0	0.0	1585.3501
LB/HR	0.0	0.0	0.0	0.0	1.5867+05
CUFT/HR	0.0	0.0	0.0	0.0	937.9342
STATE VARIABLES:					
TEMP C	MISSING	MISSING	MISSING	MISSING	269.5417
PRES PSIA	14.5038	14.5038	29.0075	29.0075	14.5038
VFRAC	MISSING	MISSING	MISSING	MISSING	0.0
LFRAC	MISSING	MISSING	MISSING	MISSING	0.0
SFRAC	MISSING	MISSING	MISSING	MISSING	1.0000
ENTHALPY:					
BTU/LBMOL	MISSING	MISSING	MISSING	MISSING	-5.0880+05
BTU/LB	MISSING	MISSING	MISSING	MISSING	-5083.6099
BTU/HR	MISSING	MISSING	MISSING	MISSING	-8.0663+08
ENTROPY:					
BTU/LBMOL-R	MISSING	MISSING	MISSING	MISSING	-49.0948
BTU/LB-R	MISSING	MISSING	MISSING	MISSING	-0.4905
DENSITY:					
LBMOL/CUFT	MISSING	MISSING	MISSING	MISSING	1.6903
LB/CUFT	MISSING	MISSING	MISSING	MISSING	169.1731
AVG MW	MISSING	MISSING	MISSING	MISSING	100.0872

STREAM SECTION

CO3HXHTR CO3LIQO CO3TOFLS CO3TOHT HYDH2OC

STREAM ID	CO3HXHTR	CO3LIQO	CO3TOFLS	CO3TOHT	HYDH2OC
FROM :	SCREWHX	CO3FLASH	SCREWHTR	CACO3WC	----
TO :	SCREWHTR	----	CO3FLASH	SCREWHX	H2OHYD1

CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	1.6702+05	8351.2237	1.6702+05	1.6702+05	3.1417+04
BTU/HR	-8.5318+08	-4.6551+07	-8.5318+08	-8.7992+08	-2.1443+08
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	VAPOR	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	463.5634	463.5634	463.5634	463.5634	1743.8851
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	8.3704-07	3.1488-06
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	8.3704-07	3.1488-06
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	463.5634	463.5634	463.5634	463.5634	1743.8851
LB/HR	8351.2237	8351.2237	8351.2237	8351.2237	3.1417+04
CUFT/HR	3.3420+05	3.3420+05	3.3420+05	134.1538	504.6749
STATE VARIABLES:					
TEMP C	269.5417	269.5417	269.5417	25.0010	25.0000
PRES PSIA	14.5038	14.5038	14.5038	14.5038	14.5038
VFRAC	1.0000	1.0000	1.0000	0.0	0.0
LFRAC	0.0	0.0	0.0	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.0042+05	-1.0042+05	-1.0042+05	-1.2296+05	-1.2296+05
BTU/LB	-5574.1914	-5574.1914	-5574.1914	-6825.3354	-6825.3373
BTU/HR	-4.6551+07	-4.6551+07	-4.6551+07	-5.7000+07	-2.1443+08
ENTROPY:					
BTU/LBMOL-R	-5.6521	-5.6521	-5.6521	-38.9707	-38.9708
BTU/LB-R	-0.3137	-0.3137	-0.3137	-2.1632	-2.1632

STREAM SECTION

CO3HXHTR CO3LIQO CO3TOFLS CO3TOHT HYDH2O (CONTINUED)

STREAM ID	CO3HXHTR	CO3LIQO	CO3TOFLS	CO3TOHT	HYDH2OC
DENSITY:					
LBMOL/CUFT	1.3871-03	1.3871-03	1.3871-03	3.4555	3.4555
LB/CUFT	2.4989-02	2.4989-02	2.4989-02	62.2511	62.2511
AVG MW	18.0153	18.0153	18.0153	18.0153	18.0153
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0

KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	1585.3501	0.0	1585.3501	1585.3501	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	1585.3501	0.0	1585.3501	1585.3501	0.0
LB/HR	1.5867+05	0.0	1.5867+05	1.5867+05	0.0
CUFT/HR	937.9342	0.0	937.9342	937.9342	0.0
STATE VARIABLES:					
TEMP C	269.5417	MISSING	269.5417	25.0010	MISSING
PRES PSIA	14.5038	14.5038	14.5038	14.5038	14.5038
VFRAC	0.0	MISSING	0.0	0.0	MISSING
LFRAC	0.0	MISSING	0.0	0.0	MISSING
SFRAC	1.0000	MISSING	1.0000	1.0000	MISSING
ENTHALPY:					
BTU/LBMOL	-5.0880+05	MISSING	-5.0880+05	-5.1908+05	MISSING
BTU/LB	-5083.6099	MISSING	-5083.6099	-5186.2339	MISSING
BTU/HR	-8.0663+08	MISSING	-8.0663+08	-8.2292+08	MISSING
ENTROPY:					
BTU/LBMOL-R	-49.0948	MISSING	-49.0948	-62.9082	MISSING
BTU/LB-R	-0.4905	MISSING	-0.4905	-0.6285	MISSING
DENSITY:					
LBMOL/CUFT	1.6903	MISSING	1.6903	1.6903	MISSING
LB/CUFT	169.1731	MISSING	169.1731	169.1731	MISSING
AVG MW	100.0872	MISSING	100.0872	100.0872	MISSING

STREAM SECTION

HYDH2OH HYDH2OW HYDPRODS KILNFEED KILNOUTH

STREAM ID	HYDH2OH	HYDH2OW	HYDPRODS	KILNFEED	KILNOUTH
FROM :	H2OHYD2	H2OHYD1	HYDRATOR	KILNHT	KILN
TO :	HYDRATOR	H2OHYD2	CAOH2SPL	KILN	CAOCO2SP
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
CONV. MAX. REL. ERR:	2.8510-11	0.0	0.0	0.0	-9.2569-13
TOTAL STREAM:					
LB/HR	3.1417+04	3.1417+04	1.2032+05	1.5867+05	1.5867+05
BTU/HR	-2.1075+08	-2.1233+08	-6.8721+08	-7.5971+08	-6.4529+08
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	MIXED	MISSING	VAPOR
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	1585.3501
N2	0.0	0.0	0.0	0.0	0.0
WATER	1743.8851	1743.8851	158.5350	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0

CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	1.8498-02	0.0	0.0
H3O+	1.9438-05	1.0255-05	9.3958-11	0.0	0.0
CAOH+	0.0	0.0	9.6269-03	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	1585.3220	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	1.9438-05	1.0255-05	4.6623-02	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	1743.8851	1743.8851	1743.9317	0.0	1585.3501
LB/HR	3.1417+04	3.1417+04	1.2032+05	0.0	6.9771+04
CUFT/HR	521.4259	512.4602	886.8468	0.0	1.1859+06
STATE VARIABLES:					
TEMP C	90.0000	62.2200	90.0000	MISSING	850.0000
PRES PSIA	14.5038	14.5038	14.5038	14.5038	29.0075
VFRAC	0.0	0.0	0.0	MISSING	1.0000
LFRAC	1.0000	1.0000	9.0950-02	MISSING	0.0
SFRAC	0.0	0.0	0.9091	MISSING	0.0
ENTHALPY:					
BTU/LBMOL	-1.2085+05	-1.2176+05	-3.9406+05	MISSING	-1.5200+05
BTU/LB	-6708.3745	-6758.4570	-5711.5472	MISSING	-3453.8392
BTU/HR	-2.1075+08	-2.1233+08	-6.8721+08	MISSING	-2.4098+08
ENTROPY:					
BTU/LBMOL-R	-35.4193	-36.8552	-63.1645	MISSING	14.1481
BTU/LB-R	-1.9661	-2.0458	-0.9155	MISSING	0.3215

STREAM SECTION

HYDH2OH HYDH2OW HYDPRODS KILNFEED KILNOU (CONTINUED)

STREAM ID	HYDH2OH	HYDH2OW	HYDPRODS	KILNFEED	KILNOUTH
DENSITY:					
LBMOL/CUFT	3.3445	3.4030	1.9664	MISSING	1.3368-03
LB/CUFT	60.2513	61.3054	135.6704	MISSING	5.8831-02
AVG MW	18.0153	18.0153	68.9929	MISSING	44.0098
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	1585.3501
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	1585.3501	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	1.5434-12

KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	0.0	0.0	0.0	1585.3501	1585.3501
LB/HR	0.0	0.0	0.0	1.5867+05	8.8902+04
CUFT/HR	0.0	0.0	0.0	937.9342	425.7196
STATE VARIABLES:					
TEMP C	MISSING	MISSING	MISSING	850.0000	850.0000
PRES PSIA	MISSING	14.5038	14.5038	14.5038	29.0075
VFRAC	MISSING	MISSING	MISSING	0.0	0.0
LFRAC	MISSING	MISSING	MISSING	0.0	0.0
SFRAC	MISSING	MISSING	MISSING	1.0000	1.0000
ENTHALPY:					
BTU/LBMOL	MISSING	MISSING	MISSING	-4.7921+05	-2.5503+05
BTU/LB	MISSING	MISSING	MISSING	-4787.9053	-4547.7721
BTU/HR	MISSING	MISSING	MISSING	-7.5971+08	-4.0431+08
ENTROPY:					
BTU/LBMOL-R	MISSING	MISSING	MISSING	-28.7103	-9.6073
BTU/LB-R	MISSING	MISSING	MISSING	-0.2869	-0.1713
DENSITY:					
LBMOL/CUFT	MISSING	MISSING	MISSING	1.6903	3.7239
LB/CUFT	MISSING	MISSING	MISSING	169.1731	208.8283
AVG MW	MISSING	MISSING	MISSING	100.0872	56.0774

STREAM SECTION

KOHFEED KOHPURGE KOHREC KOHRECIN KOHSOLHP

STREAM ID	KOHFEED	KOHPURGE	KOHREC	KOHRECIN	KOHSOLHP
FROM :	----	KOHSPLIT	KCACENT	KOHSPLIT	KOHPUMP
TO :	KOHMIX	----	KOHSPLIT	KOHMIX	SCRUBBER
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
CONV. MAX. REL. ERR:	0.0	0.0	0.0	0.0	-1.9350-04
TOTAL STREAM:					
LB/HR	8.7437+05	2.0554+06	4.1109+07	3.9053+07	3.9973+07
BTU/HR	-2.8453+09	-1.1210+10	-2.2421+11	-2.1300+11	-2.1615+11
SUBSTREAM: MIXED					
PHASE:	SOLID	LIQUID	LIQUID	LIQUID	MIXED
COMPONENTS: LBMOL/HR					
O2	0.0	8.9184-02	1.7837	1.6945	1.6945
CO2	0.0	1.7600-13	3.5200-12	3.3440-12	5.7906-12
N2	0.0	0.1714	3.4286	3.2571	3.2571
WATER	0.0	6.5332+04	1.3066+06	1.2413+06	1.2438+06
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	2.2804-06	4.5607-05	4.3327-05	3.6857-05
H3O+	0.0	1.3139-14	2.6277-13	2.4963-13	3.3801-13
CAOH+	0.0	1.1248-03	2.2495-02	2.1371-02	1.9617-02
K+	0.0	1.5507+04	3.1014+05	2.9463+05	3.1021+05
KOH(S)	1.5584+04	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	1.7596-03
HCO3-	0.0	3.7769-03	7.5538-02	7.1761-02	6.9036-02

OH-	0.0	1.4858+04	2.9716+05	2.8230+05	2.9788+05
CO3--	0.0	324.5197	6490.3947	6165.8750	6165.8777
TOTAL FLOW:					
LBMOL/HR	1.5584+04	9.6021+04	1.9204+06	1.8244+06	1.8581+06
LB/HR	8.7437+05	2.0554+06	4.1109+07	3.9053+07	3.9973+07
CUFT/HR	6852.5280	2.3211+04	4.6422+05	4.4101+05	4.4782+05
STATE VARIABLES:					
TEMP C	25.0000	25.0013	25.0013	25.0013	30.4992
PRES PSIA	14.5038	14.5038	14.5038	14.5038	29.0075
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	0.0	1.0000	1.0000	1.0000	1.0000
SFRAC	1.0000	0.0	0.0	0.0	9.4697-10
ENTHALPY:					
BTU/LBMOL	-1.8258+05	-1.1675+05	-1.1675+05	-1.1675+05	-1.1633+05
BTU/LB	-3254.1794	-5453.9753	-5453.9753	-5453.9753	-5407.3900
BTU/HR	-2.8453+09	-1.1210+10	-2.2421+11	-2.1300+11	-2.1615+11
ENTROPY:					
BTU/LBMOL-R	-36.7042	-32.1545	-32.1545	-32.1545	-31.6720
BTU/LB-R	-0.6542	-1.5021	-1.5021	-1.5021	-1.4722

STREAM SECTION

KOHFEED KOHPURGE KOHREC KOHRECIN KOHSOLH (CONTINUED)

STREAM ID	KOHFEED	KOHPURGE	KOHREC	KOHRECIN	KOHSOLHP
DENSITY:					
LBMOL/CUFT	2.2742	4.1369	4.1369	4.1369	4.1492
LB/CUFT	127.5978	88.5548	88.5548	88.5548	89.2624
AVG MW	56.1056	21.4061	21.4061	21.4061	21.5129

STREAM SECTION

KOHSOLLP LIQOUT PELLFEED PELLTOUT PELPRODO

STREAM ID	KOHSOLLP	LIQOUT	PELLFEED	PELLTOUT	PELPRODO
FROM :	KOHMIX	AIRSEP	PELLMIX	PELLETRX	CACO3SPL
TO :	KOHPUMP	PELLMIX	PELLETRX	CACO3SPL	KCACENT
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
CONV. MAX. REL. ERR:	0.0	0.0	0.0	1.9770-04	0.0
TOTAL STREAM:					
LB/HR	3.9973+07	4.1160+07	4.1976+07	4.1976+07	4.1817+07
BTU/HR	-2.1615+11	-2.2438+11	-2.2880+11	-2.2881+11	-2.2799+11
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	MIXED	MIXED	MIXED
COMPONENTS: LBMOL/HR					
O2	1.6945	1.7841	1.7926	1.7927	1.7927
CO2	5.8009-12	3.7639-12	3.7089-12	3.5460-12	3.5380-12
N2	3.2571	3.4293	3.4457	3.4458	3.4458
WATER	1.2438+06	1.3066+06	1.3132+06	1.3132+06	1.3132+06
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	3.6862-05	4.4338-05	4.8100-05	4.5872-05	4.5797-05
H3O+	3.3758-13	2.7438-13	2.8037-13	2.6406-13	2.6384-13
CAOH+	1.9618-02	2.1371-02	2.3159-02	2.2626-02	2.2608-02
K+	3.1021+05	3.0704+05	3.0852+05	3.1169+05	3.1169+05
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0

CACO3(S)	0.0	0.0	4071.4488	4033.4719	4047.1865
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	1.7588-03	0.0	2864.7422	1316.6698	1302.9552
HCO3-	6.9027-02	7.8796-02	7.6249-02	7.6092-02	7.6111-02
OH-	2.9788+05	2.9365+05	2.9553+05	2.9862+05	2.9865+05
CO3--	6165.8777	6695.1773	6499.5430	6536.7242	6523.0096
TOTAL FLOW:					
LBMOL/HR	1.8581+06	1.9140+06	1.9307+06	1.9354+06	1.9354+06
LB/HR	3.9973+07	4.0941+07	4.1757+07	4.1817+07	4.1817+07
CUFT/HR	4.4794+05	4.6316+05	4.6940+05	4.6963+05	4.6963+05
STATE VARIABLES:					
TEMP C	30.4838	25.0033	25.1692	25.0000	25.0013
PRES PSIA	14.5038	14.5038	14.5038	14.5038	14.5038
VFRAC	1.4676-07	0.0	8.0628-09	0.0	0.0
LFRAC	1.0000	1.0000	0.9964	0.9972	0.9972
SFRAC	9.4654-10	0.0	3.5926-03	2.7647-03	2.7643-03
ENTHALPY:					
BTU/LBMOL	-1.1633+05	-1.1682+05	-1.1810+05	-1.1780+05	-1.1780+05
BTU/LB	-5407.4309	-5461.4826	-5460.5330	-5451.9887	-5451.9999
BTU/HR	-2.1615+11	-2.2360+11	-2.2801+11	-2.2799+11	-2.2799+11
ENTROPY:					
BTU/LBMOL-R	-31.6724	-32.1885	-32.3082	-32.2442	-32.2444
BTU/LB-R	-1.4723	-1.5049	-1.4938	-1.4924	-1.4924

STREAM SECTION

KOHSOLLP LIQOUT PELLFEED PELLTOUT PELPRO (CONTINUED)

STREAM ID	KOHSOLLP	LIQOUT	PELLFEED	PELLTOUT	PELPRODO
DENSITY:					
LBMOL/CUFT	4.1481	4.1326	4.1131	4.1211	4.1211
LB/CUFT	89.2377	88.3943	88.9568	89.0413	89.0413
AVG MW	21.5129	21.3896	21.6277	21.6062	21.6061
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL				
COMPONENTS: LBMOL/HR					
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	0.0	0.0	0.0
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	1585.3501	0.0
K2CO3(S)	0.0	1585.3501	1585.3501	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	0.0	0.0	0.0	0.0
OH-	0.0	0.0	0.0	0.0	0.0
CO3--	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	0.0	1585.3501	1585.3501	1585.3501	0.0
LB/HR	0.0	2.1910+05	2.1910+05	1.5867+05	0.0
CUFT/HR	0.0	761.8462	761.8462	937.9342	0.0

STATE VARIABLES:						
TEMP	C	MISSING	25.0033	25.1692	25.0000	MISSING
PRES	PSIA	14.5038	14.5038	14.5038	14.5038	MISSING
VFRAC		MISSING	0.0	0.0	0.0	MISSING
LFRAC		MISSING	0.0	0.0	0.0	MISSING
SFRAC		MISSING	1.0000	1.0000	1.0000	MISSING
ENTHALPY:						
BTU/LBMOL		MISSING	-4.9485+05	-4.9484+05	-5.1908+05	MISSING
BTU/LB		MISSING	-3580.5253	-3580.4663	-5186.2343	MISSING
BTU/HR		MISSING	-7.8451+08	-7.8450+08	-8.2292+08	MISSING
ENTROPY:						
BTU/LBMOL-R		MISSING	-70.1114	-70.0962	-62.9082	MISSING
BTU/LB-R		MISSING	-0.5073	-0.5072	-0.6285	MISSING
DENSITY:						
LBMOL/CUFT		MISSING	2.0809	2.0809	1.6903	MISSING
LB/CUFT		MISSING	287.5969	287.5969	169.1731	MISSING
AVG MW		MISSING	138.2058	138.2058	100.0872	MISSING

STREAM SECTION

SATAIR SATLIQUI SATVAPOR SATWATER SCRUBH2O

STREAM ID	SATAIR	SATLIQUI	SATVAPOR	SATWATER	SCRUBH2O
FROM :	----	SATFLASH	SATFLASH	----	----
TO :	SATFLASH	----	----	SATFLASH	KOHMIX
CLASS:	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD	MIXCISLD
TOTAL STREAM:					
LB/HR	220.4623	2.2042+04	224.5163	2.2046+04	4.5864+04
BTU/HR	-539.4888	-1.5044+08	-2.6775+04	-1.5047+08	-3.1304+08
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	VAPOR	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
O2	1.6029	5.6246-03	1.5973	0.0	0.0
CO2	3.0560-03	2.6357-04	2.7420-03	0.0	0.0
N2	6.0341	1.0830-02	6.0233	0.0	0.0
WATER	0.0	1223.4988	0.2526	1223.7515	2545.8321
KOH	0.0	0.0	0.0	0.0	0.0
K2CO3	0.0	0.0	0.0	0.0	0.0
CACO3	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
CA(OH)2	0.0	0.0	0.0	0.0	0.0
CA++	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	5.0560-05	0.0	2.2096-06	4.5968-06
CAOH+	0.0	0.0	0.0	0.0	0.0
K+	0.0	0.0	0.0	0.0	0.0
KOH(S)	0.0	0.0	0.0	0.0	0.0
KOH*W(S)	0.0	0.0	0.0	0.0	0.0
KOH:2(S)	0.0	0.0	0.0	0.0	0.0
CACO3(S)	0.0	0.0	0.0	0.0	0.0
K2CO3(S)	0.0	0.0	0.0	0.0	0.0
KHCO3(S)	0.0	0.0	0.0	0.0	0.0
CAOH2(S)	0.0	0.0	0.0	0.0	0.0
HCO3-	0.0	5.0461-05	0.0	0.0	0.0
OH-	0.0	9.6786-08	0.0	2.2096-06	4.5968-06
CO3--	0.0	1.0311-09	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	7.6401	1223.5156	7.8759	1223.7515	2545.8321
LB/HR	220.4623	2.2042+04	224.5163	2.2046+04	4.5864+04
CUFT/HR	3032.3588	354.0992	3125.3349	354.1499	736.7558
STATE VARIABLES:					
TEMP	C	25.0000	25.0000	25.0000	25.0000	25.0000
PRES	PSIA	14.5038	14.5038	14.5038	14.5038	14.5038
VFRAC		1.0000	0.0	1.0000	0.0	0.0
LFRAC		0.0	1.0000	0.0	1.0000	1.0000

SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-70.6129	-1.2296+05	-3399.6111	-1.2296+05	-1.2296+05
BTU/LB	-2.4471	-6825.1872	-119.2571	-6825.3373	-6825.3373
BTU/HR	-539.4888	-1.5044+08	-2.6775+04	-1.5047+08	-3.1304+08
ENTROPY:					
BTU/LBMOL-R	1.0489	-38.9702	0.9558	-38.9708	-38.9708
BTU/LB-R	3.6349-02	-2.1632	3.3529-02	-2.1632	-2.1632

STREAM SECTION

SATAIR SATLIQUI SATVAPOR SATWATER SCRUBH (CONTINUED)

STREAM ID	SATAIR	SATLIQUI	SATVAPOR	SATWATER	SCRUBH2O
DENSITY:					
LBMOL/CUFT	2.5195-03	3.4553	2.5200-03	3.4555	3.4555
LB/CUFT	7.2703-02	62.2486	7.1838-02	62.2511	62.2511
AVG MW	28.8560	18.0154	28.5066	18.0153	18.0153

STREAM SECTION

SCRUBOUT WETCAKEW

STREAM ID	SCRUBOUT	WETCAKEW
FROM :	SCRUBBER	----
TO :	AIRSEP	CACO3WC
CLASS:	MIXCISLD	MIXCISLD
TOTAL STREAM:		
LB/HR	1.9473+08	8351.2237
BTU/HR	-2.3117+11	-5.7000+07
SUBSTREAM: MIXED		
PHASE:	MIXED	LIQUID
COMPONENTS: LBMOL/HR		
O2	1.1087+06	0.0
CO2	3.0855-07	0.0
N2	4.1737+06	0.0
WATER	1.3717+06	463.5634
KOH	0.0	0.0
K2CO3	0.0	0.0
CACO3	0.0	0.0
CAO	0.0	0.0
CA(OH)2	0.0	0.0
CA++	4.4338-05	0.0
H3O+	2.7431-13	8.3701-07
CAOH+	2.1371-02	0.0
K+	3.0704+05	0.0
KOH(S)	0.0	0.0
KOH*W(S)	0.0	0.0
KOH:2(S)	0.0	0.0
CACO3(S)	0.0	0.0
K2CO3(S)	0.0	0.0
KHCO3(S)	0.0	0.0
CAOH2(S)	0.0	0.0
HCO3-	7.8796-02	0.0
OH-	2.9365+05	8.3701-07
CO3--	6695.1773	0.0
TOTAL FLOW:		
LBMOL/HR	7.2615+06	463.5634
LB/HR	1.9451+08	8351.2237
CUFT/HR	2.1227+09	134.1538
STATE VARIABLES:		
TEMP C	25.0000	25.0000

PRES	PSIA	14.5038	14.5038
VFRAC		0.7364	0.0
LFRAC		0.2636	1.0000
SFRAC		0.0	0.0
ENTHALPY:			
BTU/LBMOL		-3.1727+04	-1.2296+05
BTU/LB		-1184.4391	-6825.3373
BTU/HR		-2.3038+11	-5.7000+07
ENTROPY:			
BTU/LBMOL-R		-7.7254	-38.9708
BTU/LB-R		-0.2884	-2.1632

STREAM SECTION

SCRUBOUT WETCAKEW (CONTINUED)

STREAM ID	SCRUBOUT	WETCAKEW
DENSITY:		
LBMOL/CUFT	3.4209-03	3.4555
LB/CUFT	9.1632-02	62.2511
AVG MW	26.7864	18.0153
SUBSTREAM: CISOLID	STRUCTURE: CONVENTIONAL	
COMPONENTS: LBMOL/HR		
O2	0.0	0.0
CO2	0.0	0.0
N2	0.0	0.0
WATER	0.0	0.0
KOH	0.0	0.0
K2CO3	0.0	0.0
CACO3	0.0	0.0
CAO	0.0	0.0
CA(OH)2	0.0	0.0
CA++	0.0	0.0
H3O+	0.0	0.0
CAOH+	0.0	0.0
K+	0.0	0.0
KOH(S)	0.0	0.0
KOH*W(S)	0.0	0.0
KOH:2(S)	0.0	0.0
CACO3(S)	0.0	0.0
K2CO3(S)	1585.3501	0.0
KHCO3(S)	0.0	0.0
CAOH2(S)	0.0	0.0
HCO3-	0.0	0.0
OH-	0.0	0.0
CO3--	0.0	0.0
TOTAL FLOW:		
LBMOL/HR	1585.3501	0.0
LB/HR	2.1910+05	0.0
CUFT/HR	761.8462	0.0
STATE VARIABLES:		
TEMP C	25.0000	MISSING
PRES PSIA	14.5038	14.5038
VFRAC	0.0	MISSING
LFRAC	0.0	MISSING
SFRAC	1.0000	MISSING
ENTHALPY:		
BTU/LBMOL	-4.9485+05	MISSING
BTU/LB	-3580.5265	MISSING
BTU/HR	-7.8451+08	MISSING
ENTROPY:		
BTU/LBMOL-R	-70.1117	MISSING
BTU/LB-R	-0.5073	MISSING

```
 DENSITY:
   LBMOL/CUFT             2.0809    MISSING
   LB/CUFT              287.5969    MISSING
 AVG MW                 138.2058    MISSING
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                            PROBLEM STATUS SECTION

 BLOCK STATUS
 ------------

 ********************************************************************************
 *                                                                              *
 * Calculations were completed with warnings                                    *
 *                                                                              *
 * The following Unit Operation blocks were                                     *
 * completed with warnings:                                                     *
 *   CAOHX     PELLETRX                                                         *
 *                                                                              *
 * All Transfer blocks were completed normally                                  *
 *                                                                              *
 * Initial enthalpy calculations completed with simulation warnings             *
 * for the following streams:                                                   *
 *   SATAIR                                                                     *
 *                                                                              *
 * All Convergence blocks were completed normally                               *
 *                                                                              *
 * All Sensitivity blocks were completed normally                               *
 *                                                                              *
 * The following Calculator blocks were                                         *
 * completed with warnings:                                                     *
 *   INPUTS                                                                     *
 *                                                                              *
 ********************************************************************************









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 + +                                                                         + +
 + +                     ASPEN PLUS CALCULATION REPORT                       + +
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 ASPEN TECHNOLOGY, INC.                U.S.A. 888/996-7100
 781/221-6400                          EUROPE (44) 1189-226555

 PLATFORM: WINDOWS                                    APRIL 14, 2019
 VERSION: 36.0   Build 250 Patchlevel 1               SUNDAY
 INSTALLATION:                                        11:14:35 P.M.

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RUN CONTROL SECTION

RUN CONTROL INFORMATION

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TYPE OF RUN: NEW

INPUT FILE NAME: _0002wvb.inm

OUTPUT PROBLEM DATA FILE NAME: _0002wvb
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:
  NUMBER OF FILE RECORDS (PSIZE) =   0
  NUMBER OF IN-CORE RECORDS   =   256
PSIZE NEEDED FOR SIMULATION   =   256

CALLING PROGRAM NAME: apmain
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V10.0\Engine\\xeq

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
H2IN	----	FEEDMIX	CO22BAR	----	COMP1
C1HXCWI	----	COMP1HX	C2HXCWI	----	COMP2HX
FLUECWI	----	WGSFLAHX	WGSOUT	HTWGS	FLUESPLT
HPFDMX-3	FEEDMIX	COMP3HX	WGSFEED	FEEDHEAT	HTWGS
SYNTOFT	FLUEPURG	----	FLURC25	FLUEPURG	FLUECOMP
FLUEDRY	FLUFLASH	FLUEPURG	H2O	FLUFLASH	----

FEEDCOLD	HPMIX	ECONOM1	CO26HOT	COMP1	COMP1HX
CO218HOT	COMP2	COMP2HX	CO225HOT	COMP3	COMP3HX
CO26COLD	COMP1HX	COMP2	C1HXCWO	COMP1HX	----
CO218CLD	COMP2HX	COMP3	C2HXCWO	COMP2HX	----
CO225CLD	COMP3HX	FEEDMIX	HPFD3-MX	COMP3HX	HPMIX
FLUECLD2	ECONOM2	FLUEMIX	FEEDHOT	ECONOM2	FEEDHEAT
FLUECLD1	ECONOM1	FLUEMIX	FEEDWARM	ECONOM1	ECONOM2
FLUEHOT1	FLUESPLT	ECONOM1	FLUEHOT2	FLUESPLT	ECONOM2
FLU2HX	FLUEMIX	WGSFLAHX	HX2FLASH	WGSFLAHX	FLUFLASH
FLUECWO	WGSFLAHX	----	FLURC255	FLUECOMP	HPMIX

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
HTWGS	WGSFEED	WGSOUT
FEEDMIX	H2IN CO225CLD	HPFDMX-3
FEEDHEAT	FEEDHOT	WGSFEED
FLUEPURG	FLUEDRY	SYNTOFT FLURC25
FLUFLASH	HX2FLASH	FLUEDRY H2O
HPMIX	HPFD3-MX FLURC255	FEEDCOLD
COMP1	CO22BAR	CO26HOT
COMP2	CO26COLD	CO218HOT
COMP3	CO218CLD	CO225HOT
COMP1HX	CO26HOT C1HXCWI	CO26COLD C1HXCWO
COMP2HX	CO218HOT C2HXCWI	CO218CLD C2HXCWO
COMP3HX	CO225HOT HPFDMX-3	CO225CLD HPFD3-MX
ECONOM2	FLUEHOT2 FEEDWARM	FLUECLD2 FEEDHOT
ECONOM1	FLUEHOT1 FEEDCOLD	FLUECLD1 FEEDWARM
FLUESPLT	WGSOUT	FLUEHOT1 FLUEHOT2
FLUEMIX	FLUECLD1 FLUECLD2	FLU2HX
WGSFLAHX	FLU2HX FLUECWI	HX2FLASH FLUECWO
FLUECOMP	FLURC25	FLURC255

FLOWSHEET SECTION

CONVERGENCE STATUS SUMMARY

DESIGN-SPEC SUMMARY

DESIGN SPEC	ERROR	TOLERANCE	ERR/TOL	VARIABLE	STAT	CONV BLOCK
C1HXCW	-0.49882E-05	0.10000E-02	-0.49882E-02	0.10830E+06	#	CHXCOMP1
C2HXCW	-0.30551E-03	0.10000E-02	-0.30551	0.10393E+06	#	CHXCOMP2
FLASTEMP	0.34493E-03	0.10000E-02	0.34493	84.320	#	$OLVER02
FLUEHXCW	0.41415E-03	0.10000E-02	0.41415	0.15899E+07	#	$OLVER03
WGSTEMP	0.89728E-07	0.10000E-02	0.89728E-04	567.72	#	$OLVER04

TEAR STREAM SUMMARY

STREAM ID	VARIABLE ID	MAXIMUM ERR/TOL	MAX. ERR. RELATIVE	ABSOLUTE ERROR	STAT	CONV BLOCK
FEEDWARM	CO MOLEFLOW	0.36255	-0.36255E-04	0.48807E-05	#	CFEDWARM
HPFDMX-3	MASS ENTHALPY	0.20536	-0.20536E-04	0.14889E-05	#	CHPFDMX

```
4619      FEEDCOLD CO MOLEFLOW       0.28862      0.28862E-04  0.38852E-05  #
          CHPFEED

4620      FLUEHOT2 CO MOLEFLOW       0.57643      0.57643E-04  0.77666E-05  #
          $OLVER01

4621
4622      #  = CONVERGED
4623      *  = NOT CONVERGED
4624      LB = AT LOWER BOUNDS
4625      UB = AT UPPER BOUNDS
4626
4627    DESIGN-SPEC:  C1HXCW
4628    --------------------
4629
4630      SAMPLED VARIABLES:
4631        C1CTOUT  : TEMPERATURE IN STREAM C1HXCWO SUBSTREAM MIXED
4632
4633      SPECIFICATION:
4634        MAKE C1CTOUT APPROACH 48.8900
4635        WITHIN          0.00100000
4636
4637      MANIPULATED VARIABLES:
4638        VARY     : WATER MASSFLOW IN STREAM C1HXCWI SUBSTREAM MIXED
4639        LOWER LIMIT =          11.0231                   LB/HR
4640        UPPER LIMIT =   2,204,620.                       LB/HR
4641        FINAL VALUE =     108,302.                       LB/HR
4642
4643      VALUES OF ACCESSED FORTRAN VARIABLES:
4644        VARIABLE      VALUE AT START      FINAL VALUE     UNITS
4645                         OF LOOP
4646        --------      --------------      -----------     -----
4647        C1CTOUT         40.7574            48.8900       C
4648 FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 4
4649
4650                                FLOWSHEET SECTION
4651
4652    DESIGN-SPEC:  C2HXCW
4653    --------------------
4654
4655      SAMPLED VARIABLES:
4656        C2CTOUT  : TEMPERATURE IN STREAM C2HXCWO SUBSTREAM MIXED
4657
4658      SPECIFICATION:
4659        MAKE C2CTOUT APPROACH 48.8900
4660        WITHIN          0.00100000
4661
4662      MANIPULATED VARIABLES:
4663        VARY     : WATER MASSFLOW IN STREAM C2HXCWI SUBSTREAM MIXED
4664        LOWER LIMIT =          11.0231                   LB/HR
4665        UPPER LIMIT =   2,204,620.                       LB/HR
4666        FINAL VALUE =     103,930.                       LB/HR
4667
4668      VALUES OF ACCESSED FORTRAN VARIABLES:
4669        VARIABLE      VALUE AT START      FINAL VALUE     UNITS
4670                         OF LOOP
4671        --------      --------------      -----------     -----
4672        C2CTOUT         40.4013            48.8897       C
4673
4674    DESIGN-SPEC:  FLASTEMP
4675    ----------------------
4676
4677      SAMPLED VARIABLES:
4678        H2OFLDRY : WATER MASSFRAC IN STREAM FLUEDRY SUBSTREAM MIXED
4679
4680      SPECIFICATION:
```

```
      MAKE H2OFLDRY APPROACH 0.050000
      WITHIN          0.00100000

    MANIPULATED VARIABLES:
      VARY     : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FLUFLASH
      LOWER LIMIT =          50.0000                   C
      UPPER LIMIT =         150.000                    C
      FINAL VALUE =          84.3204                   C

    VALUES OF ACCESSED FORTRAN VARIABLES:
      VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                       OF LOOP
      --------      --------------      -----------     -----
      H2OFLDRY       0.503449E-01       0.503449E-01

 DESIGN-SPEC:  FLUEHXCW
 ----------------------

    SAMPLED VARIABLES:
      CWOUT    : TEMPERATURE IN STREAM FLUECWO SUBSTREAM MIXED

    SPECIFICATION:
      MAKE CWOUT APPROACH 48.8900
      WITHIN          0.00100000
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                                FLOWSHEET SECTION

 DESIGN-SPEC:  FLUEHXCW (CONTINUED)

    MANIPULATED VARIABLES:
      VARY     : WATER MASSFLOW IN STREAM FLUECWI SUBSTREAM MIXED
      LOWER LIMIT =     992,080.                      LB/HR
      UPPER LIMIT =   1,653,470.                      LB/HR
      FINAL VALUE =   1,589,930.                      LB/HR

    VALUES OF ACCESSED FORTRAN VARIABLES:
      VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                       OF LOOP
      --------      --------------      -----------     -----
      CWOUT           48.8904            48.8904       C

 DESIGN-SPEC:  WGSTEMP
 ---------------------

    SAMPLED VARIABLES:
      WGSOUT   : TEMPERATURE IN STREAM WGSOUT SUBSTREAM MIXED

    SPECIFICATION:
      MAKE WGSOUT APPROACH 500.000
      WITHIN          0.00100000

    MANIPULATED VARIABLES:
      VARY     : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FEEDHEAT
      LOWER LIMIT =         380.000                   C
      UPPER LIMIT =         900.000                   C
      FINAL VALUE =         567.720                   C

    VALUES OF ACCESSED FORTRAN VARIABLES:
      VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                       OF LOOP
      --------      --------------      -----------     -----
      WGSOUT          500.004            500.000       C

 CALCULATOR BLOCK:   FLASHTMP
 ----------------------------
```

```
4747
4748      SAMPLED VARIABLES:
4749        FLASHTMP : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FLUFLASH
4750        HXHOUT   : SENTENCE=PARAM VARIABLE=T-HOT IN UOS BLOCK WGSFLAHX
4751
4752      FORTRAN STATEMENTS:
4753           HXHOUT = FLASHTMP
4754
4755      EXECUTE BEFORE BLOCK WGSFLAHX
4756
4757      VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:
4758        VARIABLE        VALUE READ      VALUE WRITTEN    UNITS
4759        --------        ----------      -------------    -----
4760        FLASHTMP         84.3204                         C
4761        HXHOUT           84.3204          84.3204        C
4762 FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 6
4763
4764                                FLOWSHEET SECTION
4765
4766    CALCULATOR BLOCK:   H2IN
4767    ------------------------
4768
4769      SAMPLED VARIABLES:
4770        H2IN     : H2 MOLEFLOW IN STREAM H2IN SUBSTREAM MIXED
4771        CO2IN    : CO2 MOLEFLOW IN STREAM CO225CLD SUBSTREAM MIXED
4772        FLUERECC : CO2 MOLEFLOW IN STREAM FLURC25 SUBSTREAM MIXED
4773        FLUERECH : H2 MOLEFLOW IN STREAM FLURC25 SUBSTREAM MIXED
4774
4775      FORTRAN STATEMENTS:
4776           H2IN = 5*(CO2IN + FLUERECC) - FLUERECH
4777
4778      EXECUTE BEFORE BLOCK FEEDMIX
4779
4780      VALUES OF ACCESSED FORTRAN VARIABLES ON MOST RECENT SIMULATION PASS:
4781        VARIABLE        VALUE READ      VALUE WRITTEN    UNITS
4782        --------        ----------      -------------    -----
4783        H2IN             3595.90          3595.90        KMOL/HR
4784        CO2IN            719.181                         KMOL/HR
4785        FLUERECC         0.00000                         KMOL/HR
4786        FLUERECH         0.00000                         KMOL/HR
4787
4788    CONVERGENCE BLOCK:  CFEDWARM
4789    ----------------------------
4790        Tear Stream  :  FEEDWARM
4791        Tolerance used:  0.100D-03
4792        Trace molefrac:  0.100D-05
4793
4794        MAXIT =   30 WAIT =   2
4795        METHOD: BROYDEN       STATUS: CONVERGED
4796        TOTAL NUMBER OF ITERATIONS:     8
4797
4798                             *** FINAL VALUES ***
4799
4800   VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
       VALUE       PREV VALUE       ERR/TOL
4801   ----  ---------------  -------- -------- -------- -------- -------- -----------
       ------------   ------------   ------------
4802      1  TOTAL MOLEFLOW   FEEDWARM MIXED                                LBMOL/HR
          1.8141+04      1.8141+04     -9.8234-02
4803      2  MOLE-FLOW        FEEDWARM MIXED    CO2                       LBMOL/HR
          2094.3147      2094.3138      4.6399-03
4804      3  MOLE-FLOW        FEEDWARM MIXED    CO                        LBMOL/HR
          1068.4013      1068.4400        -0.3625
4805      4  MOLE-FLOW        FEEDWARM MIXED    O2                        LBMOL/HR
          0.0            0.0             0.0
4806      5  MOLE-FLOW        FEEDWARM MIXED    N2                        LBMOL/HR
```

```
      0.0            0.0            0.0
4807  6  MOLE-FLOW        FEEDWARM MIXED    H2                            LBMOL/HR
      1.4783+04      1.4784+04     -9.2229-02
4808  7  MOLE-FLOW        FEEDWARM MIXED    CH4                           LBMOL/HR
      0.0            0.0            0.0
4809  8  MOLE-FLOW        FEEDWARM MIXED    WATER                         LBMOL/HR
      194.6285       194.6325        -0.2104
4810  9  PRESSURE         FEEDWARM MIXED                                  PSIA
      362.5943       362.5943         0.0
4811 10  MASS ENTHALPY    FEEDWARM MIXED                                  BTU/LB
     -2303.7007     -2303.6897     -4.7930-02
4812
4813                          *** ITERATION HISTORY ***
4814 FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 7
4815
4816                               FLOWSHEET SECTION
4817
4818  CONVERGENCE BLOCK:  CFEDWARM (CONTINUED)
4819
4820      TEAR STREAMS AND TEAR VARIABLES:
4821
4822      ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
         ATTRIBUT ELEMENT
4823      ---------   ----------- ----  ---------      ---------------- -------- --------
         -------- -------
4824           1      0.1000E+07     9  FEEDWARM       PRESSURE
               MIXED
4825           2      0.1000E+05     8  FEEDWARM       MOLE-FLOW        MIXED
               WATER
4826           3       6150.         3  FEEDWARM       MOLE-FLOW        MIXED
               CO
4827           4       1000.         3  FEEDWARM       MOLE-FLOW        MIXED
               CO
4828           5       112.5         3  FEEDWARM       MOLE-FLOW        MIXED
               CO
4829           6       10.78         3  FEEDWARM       MOLE-FLOW        MIXED
               CO
4830           7       1.314         3  FEEDWARM       MOLE-FLOW        MIXED
               CO
4831           8     -0.3625         3  FEEDWARM       MOLE-FLOW        MIXED
               CO
4832
4833  CONVERGENCE BLOCK:  CHPFDMX
4834  ---------------------------
4835      Tear Stream  :  HPFDMX-3
4836      Tolerance used:  0.100D-03
4837      Trace molefrac:  0.100D-05
4838
4839      MAXIT =   30 WAIT =   2
4840      METHOD: BROYDEN       STATUS: CONVERGED
4841      TOTAL NUMBER OF ITERATIONS:     4
4842
4843                          *** FINAL VALUES ***
4844
4845  VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
      VALUE       PREV VALUE       ERR/TOL
4846  ----  ---------------  -------- -------- -------- -------- -------- -----------
      ------------   ------------   ------------
4847     1  TOTAL MOLEFLOW   HPFDMX-3 MIXED                               LBMOL/HR
         9513.1326      9513.1326         0.0
4848     2  MOLE-FLOW        HPFDMX-3 MIXED    CO2                       LBMOL/HR
         1585.5221      1585.5221         0.0
4849     3  MOLE-FLOW        HPFDMX-3 MIXED    CO                        LBMOL/HR
         0.0            0.0            0.0
4850     4  MOLE-FLOW        HPFDMX-3 MIXED    O2                        LBMOL/HR
         0.0            0.0            0.0
```

```
4851      5  MOLE-FLOW        HPFDMX-3 MIXED    N2                            LBMOL/HR
          0.0            0.0            0.0
4852      6  MOLE-FLOW        HPFDMX-3 MIXED    H2                            LBMOL/HR
          7927.6105      7927.6105        0.0
4853      7  MOLE-FLOW        HPFDMX-3 MIXED    CH4                           LBMOL/HR
          0.0            0.0            0.0
4854      8  MOLE-FLOW        HPFDMX-3 MIXED    WATER                         LBMOL/HR
          0.0            0.0            0.0
4855      9  PRESSURE         HPFDMX-3 MIXED                                  PSIA
          362.5943       362.5943         0.0
4856     10  MASS ENTHALPY    HPFDMX-3 MIXED                                  BTU/LB
         -3117.1030     -3117.0389       -0.2054
4857
4858                            *** ITERATION HISTORY ***
4859
4860        TEAR STREAMS AND TEAR VARIABLES:
4861
4862        ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
            ATTRIBUT ELEMENT
4863        ---------   ----------- ----  ---------      ---------------- -------- --------
            -------- -------
4864             1      0.1000E+07     9  HPFDMX-3       PRESSURE
            MIXED
4865             2      -20.99        10  HPFDMX-3       MASS ENTHALPY
            MIXED
4866             3      -4.501        10  HPFDMX-3       MASS ENTHALPY
            MIXED
4867             4     -0.2054        10  HPFDMX-3       MASS ENTHALPY
            MIXED
4868    ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 8
4869
4870                                  FLOWSHEET SECTION
4871
4872     CONVERGENCE BLOCK:  CHPFEED
4873     ---------------------------
4874         Tear Stream  :  FEEDCOLD
4875         Tolerance used:  0.100D-03
4876         Trace molefrac:  0.100D-05
4877
4878         MAXIT =   30 WAIT =   2
4879         METHOD: BROYDEN       STATUS: CONVERGED
4880         TOTAL NUMBER OF ITERATIONS:    23
4881         NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1
4882
4883                            *** FINAL VALUES ***
4884
4885    VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
        VALUE       PREV VALUE       ERR/TOL
4886    ----  ---------------  -------- -------- -------- -------- -------- -----------
        ------------   ------------   ------------
4887       1  TOTAL MOLEFLOW   FEEDCOLD MIXED                                 LBMOL/HR
           1.8141+04      1.8141+04      5.8067-02
4888       2  MOLE-FLOW        FEEDCOLD MIXED    CO2                           LBMOL/HR
           2094.3146      2094.3147     -3.7704-04
4889       3  MOLE-FLOW        FEEDCOLD MIXED    CO                            LBMOL/HR
           1068.4321      1068.4013         0.2886
4890       4  MOLE-FLOW        FEEDCOLD MIXED    O2                            LBMOL/HR
           0.0            0.0            0.0
4891       5  MOLE-FLOW        FEEDCOLD MIXED    N2                            LBMOL/HR
           0.0            0.0            0.0
4892       6  MOLE-FLOW        FEEDCOLD MIXED    H2                            LBMOL/HR
           1.4784+04      1.4783+04      4.8818-02
4893       7  MOLE-FLOW        FEEDCOLD MIXED    CH4                           LBMOL/HR
           0.0            0.0            0.0
4894       8  MOLE-FLOW        FEEDCOLD MIXED    WATER                         LBMOL/HR
           194.6309       194.6285         0.1239
```

```
     9  PRESSURE         FEEDCOLD MIXED                                PSIA
     362.5943       362.5943         0.0
    10  MASS ENTHALPY    FEEDCOLD MIXED                                BTU/LB
    -2682.4448     -2682.4525      2.8629-02

                          *** ITERATION HISTORY ***

      TEAR STREAMS AND TEAR VARIABLES:

      ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
      ATTRIBUT ELEMENT
      ---------   ----------- ----  ---------      ---------------- -------- --------
      -------- -------
           1      0.2886         3  FEEDCOLD       MOLE-FLOW        MIXED
           CO

 CONVERGENCE BLOCK:  CHXCOMP1
 ----------------------------
      SPECS: C1HXCW
      MAXIT =   30
      PERTURBATION SIZE (% OF RANGE):  C1HXCW      1.0000
      MAXIMUM STEP SIZE (% OF RANGE):  C1HXCW      100.00
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 9

                               FLOWSHEET SECTION

 CONVERGENCE BLOCK:  CHXCOMP1 (CONTINUED)
      METHOD: BROYDEN       STATUS: CONVERGED
      TOTAL NUMBER OF ITERATIONS:    14
      NUMBER OF ITERATIONS ON LAST OUTER LOOP:    13

                          *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                            UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- ------------------------                       -----------
------------   ------------   ------------
   1  WATER MASSFLOW   C1HXCWI.MIXED.WATER.MASSFLOW                   LB/HR
   1.0830+05      1.0829+05     -4.9882-03

                          *** ITERATION HISTORY ***

      DESIGN-SPEC ID:
      C1HXCW

      ITERATED:  WATER MASSFLOW IN STREAM C1HXCWI SUBSTREAM MIXED

      ITERATION  VARIABLE         ERROR          ERR/TOL
      ---------  --------         -----          -------
           1     0.2205E+06       -8.133         -8133.
           2     0.2425E+06       -8.879         -8879.
           3      11.02     LB     117.0         0.1170E+06
           4     0.2061E+06       -7.565         -7565.
           5     0.1936E+06       -7.006         -7006.
           6     0.3664E+05        25.28         0.2528E+05
           7     0.1596E+06       -5.066         -5066.
           8     0.1390E+06       -3.457         -3457.
           9     0.9494E+05        2.127          2127.
          10     0.1117E+06      -0.4735         -473.5
          11     0.1087E+06      -0.5384E-01     -53.84
          12     0.1083E+06       0.1560E-02      1.560
          13     0.1083E+06      -0.4988E-05    -0.4988E-02

 CONVERGENCE BLOCK:  CHXCOMP2
 ----------------------------
```

```
     SPECS: C2HXCW
     MAXIT =   30
     PERTURBATION SIZE (% OF RANGE):  C2HXCW      1.0000
     MAXIMUM STEP SIZE (% OF RANGE):  C2HXCW      100.00
     METHOD: BROYDEN       STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:    14
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:    13
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 10

                                FLOWSHEET SECTION

 CONVERGENCE BLOCK:  CHXCOMP2 (CONTINUED)

                           *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                              UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- -------------------------                    -----------
------------   ------------   ------------
   1  WATER MASSFLOW   C2HXCWI.MIXED.WATER.MASSFLOW                 LB/HR
   1.0393+05      1.0379+05        -0.3055

                           *** ITERATION HISTORY ***

     DESIGN-SPEC ID:
     C2HXCW

     ITERATED:  WATER MASSFLOW IN STREAM C2HXCWI SUBSTREAM MIXED

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1     0.2205E+06       -8.489         -8489.
          2     0.2425E+06       -9.216         -9216.
          3      11.02     LB     112.9         0.1129E+06
          4     0.2051E+06       -7.906         -7906.
          5     0.1916E+06       -7.318         -7318.
          6     0.2476E+05        38.18         0.3818E+05
          7     0.1648E+06       -5.865         -5865.
          8     0.1461E+06       -4.559         -4559.
          9     0.8107E+05        4.260          4260.
         10     0.1125E+06       -1.184         -1184.
         11     0.1057E+06      -0.2548         -254.8
         12     0.1038E+06       0.1976E-01      19.76
         13     0.1039E+06      -0.3055E-03    -0.3055

 CONVERGENCE BLOCK:  $OLVER01
 ----------------------------
     Tear Stream  :  FLUEHOT2
     Tolerance used:  0.100D-03
     Trace molefrac:  0.100D-05

     MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
     QMAX =   0.0     QMIN =  -5.0
     METHOD: WEGSTEIN      STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:    21
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                           *** FINAL VALUES ***

VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------  -------- -------- -------- -------- -------- -----------
------------   ------------   ------------
   1  TOTAL MOLEFLOW   FLUEHOT2 MIXED                               LBMOL/HR
   9070.4949      9070.3131         0.2004
```

```
5009      2  MOLE-FLOW         FLUEHOT2 MIXED    CO2                           LBMOL/HR
          511.9578       511.9583     -8.6637-03
5010      3  MOLE-FLOW         FLUEHOT2 MIXED    CO                            LBMOL/HR
          1069.4190      1069.3574         0.5764
5011      4  MOLE-FLOW         FLUEHOT2 MIXED    O2                            LBMOL/HR
          0.0            0.0            0.0
5012      5  MOLE-FLOW         FLUEHOT2 MIXED    N2                            LBMOL/HR
          0.0            0.0            0.0
5013   FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 11
5014
5015                                FLOWSHEET SECTION
5016
5017    CONVERGENCE BLOCK:  $OLVER01 (CONTINUED)
5018      6  MOLE-FLOW         FLUEHOT2 MIXED    H2                            LBMOL/HR
          6856.6027      6856.4584         0.2105
5019      7  MOLE-FLOW         FLUEHOT2 MIXED    CH4                           LBMOL/HR
          0.0            0.0            0.0
5020      8  MOLE-FLOW         FLUEHOT2 MIXED    WATER                         LBMOL/HR
          632.5153       632.5390        -0.3746
5021      9  PRESSURE          FLUEHOT2 MIXED                                  PSIA
          362.5943       362.5943         0.0
5022     10  MASS ENTHALPY     FLUEHOT2 MIXED                                  BTU/LB
         -1882.6034     -1882.6501         0.2483
5023
5024                            *** ITERATION HISTORY ***
5025
5026         TEAR STREAMS AND TEAR VARIABLES:
5027
5028         ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE          SUBSTREA COMPONEN
             ATTRIBUT ELEMENT
5029         ---------   ----------- ----  ---------      ----------------- -------- --------
             -------- -------
5030              1      0.5764         3  FLUEHOT2       MOLE-FLOW         MIXED
                  CO
5031
5032    CONVERGENCE BLOCK:  $OLVER02
5033    ----------------------------
5034         SPECS: FLASTEMP
5035         MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
5036                     MAX-STEP=       100.    % OF RANGE
5037                     XTOL=       1.000000E-08
5038         THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
5039         METHOD: SECANT        STATUS: CONVERGED
5040         TOTAL NUMBER OF ITERATIONS:    37
5041         NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1
5042
5043                            *** FINAL VALUES ***
5044
5045
5046    VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                              UNIT
        VALUE       PREV VALUE       ERR/TOL
5047    ----  ---------------- -------------------------                         -----------
        ------------   ------------   ------------
5048       1  BLOCK-VAR         FLUFLASH.PARAM.TEMP                             C
           84.3204        84.3204         0.3449
5049
5050                            *** ITERATION HISTORY ***
5051
5052         DESIGN-SPEC ID:
             FLASTEMP

5053         ITERATED:  SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FLUFLASH
5054
5055         ITERATION  VARIABLE         ERROR          ERR/TOL
5056         ---------  --------         -----          -------
5057              1      84.32           0.3449E-03     0.3449
```

```
 CONVERGENCE BLOCK:  $OLVER03
 ----------------------------
     SPECS: FLUEHXCW
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/14/2019  PAGE 12

                                FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER03 (CONTINUED)
     MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
                 MAX-STEP=       100.    % OF RANGE
                 XTOL=       1.000000E-08
     THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
     METHOD: SECANT        STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:    78
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                           *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                                 UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- -------------------------                    -----------
------------   ------------   ------------
   1  WATER MASSFLOW   FLUECWI.MIXED.WATER.MASSFLOW                 LB/HR
   1.5899+06      1.5899+06         0.4141

                           *** ITERATION HISTORY ***

     DESIGN-SPEC ID:
     FLUEHXCW

     ITERATED:  WATER MASSFLOW IN STREAM FLUECWI SUBSTREAM MIXED

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1     0.1590E+07       0.4141E-03     0.4141

 CONVERGENCE BLOCK:  $OLVER04
 ----------------------------
     SPECS: WGSTEMP
     MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
                 MAX-STEP=       100.    % OF RANGE
                 XTOL=       1.000000E-08
     THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
     METHOD: SECANT        STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:    42
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     2

                           *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                                 UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- -------------------------                    -----------
------------   ------------   ------------
   1  BLOCK-VAR        FEEDHEAT.PARAM.TEMP                          C
   567.7201       567.7247      8.9728-05

                           *** ITERATION HISTORY ***
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/14/2019  PAGE 13

                                FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER04 (CONTINUED)
```

DESIGN-SPEC ID:
WGSTEMP

ITERATED: SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FEEDHEAT

ITERATION	VARIABLE	ERROR	ERR/TOL
1	567.7	0.3967E-02	3.967
2	567.7	0.8973E-07	0.8973E-04

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:

```
COMP1
CHXCOMP1 *COMP1HX
(RETURN CHXCOMP1)
COMP2
CHXCOMP2 *COMP2HX
(RETURN CHXCOMP2)
COMP3
CHPFDMX COMP3HX H2IN FEEDMIX
(RETURN CHPFDMX)
CFEDWARM
|  $OLVER01 ECONOM2
|  |  $OLVER04 FEEDHEAT HTWGS
|  |  (RETURN $OLVER04)
|  |  FLUESPLT
|  (RETURN $OLVER01)
|  CHPFEED ECONOM1 FLUEMIX
|  |  $OLVER03 FLASHTMP *WGSFLAHX
|  |  (RETURN $OLVER03)
|  |  $OLVER02 FLUFLASH
|  |  (RETURN $OLVER02)
|  |  FLUEPURG FLUECOMP HPMIX
|  (RETURN CHPFEED)
(RETURN CFEDWARM)
```

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)				
CO2	1585.52	515.124	-1070.40	0.283330E-06
CO	0.00000	1070.34	1070.40	0.502084E-04
O2	0.00000	0.00000	0.00000	0.00000
N2	0.00000	0.00000	0.00000	0.00000
H2	7927.61	6857.13	-1070.40	0.101067E-04
CH4	0.00000	0.00000	0.00000	0.00000
WATER	100035.	101105.	1070.40	-0.251031E-06

OVERALL FLOWSHEET BALANCE (CONTINUED)

TOTAL BALANCE				
MOLE(LBMOL/HR)	109548.	109548.	0.140983E-10	0.994365E-06
MASS(LB/HR)	0.188792E+07	0.188792E+07		0.651159E-06
ENTHALPY(BTU/HR)	-0.125359E+11	-0.124720E+11		-0.510060E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	69778.5	LB/HR
PRODUCT STREAMS CO2E	22670.5	LB/HR
NET STREAMS CO2E PRODUCTION	-47108.0	LB/HR

```
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION        -47108.0      LB/HR
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 15

                          PHYSICAL PROPERTIES SECTION

 COMPONENTS
 ----------

  ID       TYPE  ALIAS          NAME
   CO2      C     CO2            CARBON-DIOXIDE
   CO       C     CO             CARBON-MONOXIDE
   O2       C     O2             OXYGEN
   N2       C     N2             NITROGEN
   H2       C     H2             HYDROGEN
   CH4      C     CH4            METHANE
   WATER    C     H2O            WATER
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 16

                             U-O-S BLOCK SECTION

 BLOCK:  COMP1    MODEL: COMPR
 ------------------------------
   INLET STREAM:          CO22BAR
   OUTLET STREAM:         CO26HOT
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            1585.52         1585.52         0.00000
       MASS(LB/HR   )            69778.5         69778.5         0.00000
       ENTHALPY(BTU/HR  )     -0.267518E+09   -0.264361E+09   -0.118022E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             69778.5      LB/HR
    PRODUCT STREAMS CO2E          69778.5      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***

   POLYTROPIC COMPRESSOR USING ASME METHOD
    PRESSURE RATIO                                        3.00000
    POLYTROPIC EFFICIENCY                                 0.75000
    MECHANICAL EFFICIENCY                                 1.00000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 17

                             U-O-S BLOCK SECTION

 BLOCK:  COMP1    MODEL: COMPR (CONTINUED)

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP                1,240.86
    BRAKE      HORSEPOWER REQUIREMENT  HP                1,240.86
    NET WORK REQUIRED                  HP                1,240.86
    POWER LOSSES                       HP                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP                  896.574
    CALCULATED OUTLET PRES  PSIA                           87.0226
    CALCULATED OUTLET TEMP  C                             165.940
    EFFICIENCY (POLYTR/ISENTR) USED                       0.75000
    OUTLET VAPOR FRACTION                                 1.00000
    HEAD DEVELOPED,       FT-LBF/LB                    26,407.6
    MECHANICAL EFFICIENCY USED                            1.00000
```

```
     INLET HEAT CAPACITY RATIO                                  1.27474
     INLET VOLUMETRIC FLOW RATE , CUFT/HR                    344,129.
     OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                    154,534.
     INLET  COMPRESSIBILITY FACTOR                              1.00000
     OUTLET COMPRESSIBILITY FACTOR                              1.00000
     AV. ISENT. VOL. EXPONENT                                   1.25984
     AV. ISENT. TEMP EXPONENT                                   1.25984
     AV. ACTUAL VOL. EXPONENT                                   1.37223
     AV. ACTUAL TEMP EXPONENT                                   1.37223

 BLOCK:  COMP1HX  MODEL: HEATX
 ------------------------------
   THIS BLOCK RUNS WITH ASPEN EDR 36.2  WITH ADVANCED METHOD FOR SHELL&TUBE
   HOT SIDE:
   ---------
   INLET STREAM:             CO26HOT
   OUTLET STREAM:            CO26COLD
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
   COLD SIDE:
   ----------
   INLET STREAM:             C1HXCWI
   OUTLET STREAM:            C1HXCWO
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS


     **************************************************************************
     *                                                                        *
     *     A POTENTIAL TUBE VIBRATIEON PROBLEM IS INDICATED                   *
     *                                                                        *
     **************************************************************************

FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 18

                              U-O-S BLOCK SECTION

 BLOCK:  COMP1HX  MODEL: HEATX (CONTINUED)

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            7597.19         7597.19         0.00000
       MASS(LB/HR   )            178080.         178080.         0.00000
       ENTHALPY(BTU/HR  )     -0.100164E+10   -0.100164E+10     0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             69778.5      LB/HR
    PRODUCT STREAMS CO2E          69778.5      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   SHELL&TUBE INPUT FILE NAME                                     COMP1HX.EDR
   SHELL&TUBE PROGRAM MODE                                        SIMULATION
```

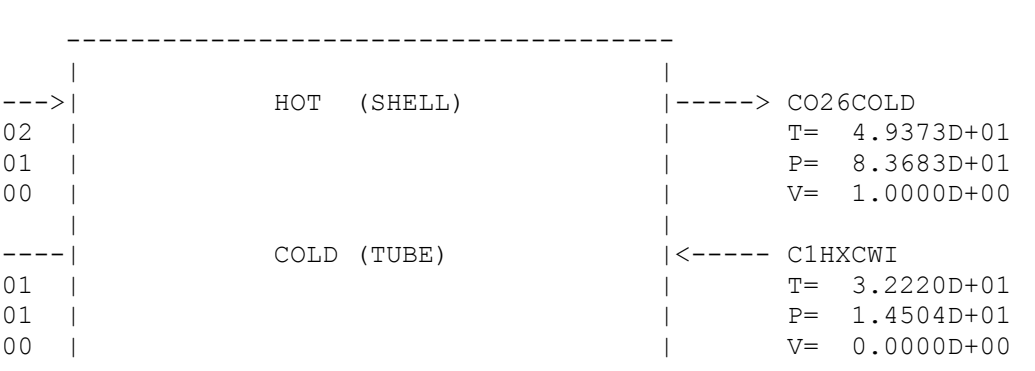
HEAT CURVE GENERATION

HOT HEAT CURVE GENERATED BY ASPEN PLUS

COLD HEAT CURVE GENERATED BY ASPEN PLUS

*** OVERALL RESULTS ***

STREAMS:



U-O-S BLOCK SECTION

BLOCK: COMP1HX MODEL: HEATX (CONTINUED)

UNIT RESULTS:

CALCULATED HEAT DUTY	BTU/HR	3246910.1518
CALCULATED (REQUIRED) AREA	SQFT	586.6332
ACTUAL EXCHANGER AREA	SQFT	588.6315
% OVER (UNDER) DESIGN		0.3406
AVERAGE COEFFICIENT	BTU/HR-SQFT-R	57.8425
UA	BTU/HR-R	33932.3163
LMTD (CORRECTED)	C	53.1599
LMTD CORRECTION FACTOR		1.0219
NUMBER OF SHELLS IN SERIES		1
NUMBER OF SHELLS IN PARALLEL		1
HIGH RHOV2 INDICATION		NO
VIBRATION INDICATION		YES

SHELLSIDE RESULTS:

MEAN SHELL METAL TEMPERATURE	C	89.4051
TOTAL PRESSURE DROP	PSI	3.3395
WINDOW PRESSURE DROP	PSI	0.6772
CROSSFLOW PRESSURE DROP	PSI	1.3059
BULK FILM COEFFICIENT	BTU/HR-SQFT-R	78.0022
WALL FILM COEFFICIENT	BTU/HR-SQFT-R	78.0022
THERMAL RESISTANCE	HR-SQFT-R/BTU	0.0128
MAXIMUM FOULING RESISTANCE	HR-SQFT-R/BTU	0.000029
FOULING RESISTANCE	HR-SQFT-R/BTU	0.0000
CROSSFLOW VELOCITY	FT/SEC	55.4987
WINDOW VELOCITY	FT/SEC	48.1604
MIDPOINT VELOCITY	FT/SEC	51.8295
SHELL ENTRANCE RHOV^2	LB/FT-SQSEC	675.7143
SHELL EXIT RHOV^2	LB/FT-SQSEC	1355.6077
BUNDLE ENTRANCE RHOV^2	LB/FT-SQSEC	1083.6933
BUNDLE EXIT RHOV^2	LB/FT-SQSEC	754.7447
FOULING % OF OVERALL RESISTANCE		0.0000
FILM % OF OVERALL RESISTANCE		74.1549
FRICTIONAL PRESSURE DROP	PSI	3.3756

TUBESIDE RESULTS:

MEAN TUBE METAL TEMPERATURE	C	50.7415
TOTAL PRESSURE DROP	PSI	0.4168
BULK FILM COEFFICIENT	BTU/HR-SQFT-R	237.7303
WALL FILM COEFFICIENT	BTU/HR-SQFT-R	237.7303
THERMAL RESISTANCE	HR-SQFT-R/BTU	0.0042

MAXIMUM FOULING RESISTANCE	HR-SQFT-R/BTU	0.000029
FOULING RESISTANCE	HR-SQFT-R/BTU	0.0000
INPUT VELOCITY	FT/SEC	0.7954
OUTLET VELOCITY	FT/SEC	0.8088
FOULING % OF OVERALL RESISTANCE		0.0000
FILM % OF OVERALL RESISTANCE		24.3311
FRICTIONAL PRESSURE DROP	PSI	0.4166

U-O-S BLOCK SECTION

HEATX COLD-TQCU COMP1HX TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: -0.4168 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	14.5038	48.8900	0.0
1.5461+05	14.5038	48.1031	0.0
3.0923+05	14.5038	47.3154	0.0
4.6384+05	14.5038	46.5271	0.0
6.1846+05	14.5038	45.7380	0.0
7.7307+05	14.5038	44.9482	0.0
9.2769+05	14.5038	44.1578	0.0
1.0823+06	14.5038	43.3666	0.0
1.2369+06	14.5038	42.5748	0.0
1.3915+06	14.5038	41.7822	0.0
1.5461+06	14.5038	40.9890	0.0
1.7008+06	14.5038	40.1951	0.0
1.8554+06	14.5038	39.4005	0.0
2.0100+06	14.5038	38.6053	0.0
2.1646+06	14.5038	37.8094	0.0
2.3192+06	14.5038	37.0128	0.0
2.4738+06	14.5038	36.2156	0.0
2.6285+06	14.5038	35.4178	0.0
2.7831+06	14.5038	34.6193	0.0
2.9377+06	14.5038	33.8201	0.0
3.0923+06	14.5038	33.0204	0.0
3.2469+06	14.5038	32.2200	0.0

U-O-S BLOCK SECTION

HEATX HOT-TQCUR COMP1HX TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC

BTU/HR	PSIA	C	
0.0	87.0226	165.9401	1.0000
1.5461+05	87.0226	160.6491	1.0000
3.0923+05	87.0226	155.3371	1.0000
4.6384+05	87.0226	150.0037	1.0000
6.1846+05	87.0226	144.6481	1.0000
7.7307+05	87.0226	139.2698	1.0000
9.2769+05	87.0226	133.8680	1.0000
1.0823+06	87.0226	128.4419	1.0000
1.2369+06	87.0226	122.9907	1.0000
1.3915+06	87.0226	117.5136	1.0000
1.5461+06	87.0226	112.0096	1.0000
1.7008+06	87.0226	106.4779	1.0000
1.8554+06	87.0226	100.9174	1.0000
2.0100+06	87.0226	95.3269	1.0000
2.1646+06	87.0226	89.7055	1.0000
2.3192+06	87.0226	84.0517	1.0000
2.4738+06	87.0226	78.3644	1.0000
2.6285+06	87.0226	72.6421	1.0000
2.7831+06	87.0226	66.8835	1.0000
2.9377+06	87.0226	61.0870	1.0000
3.0923+06	87.0226	55.2508	1.0000
3.2469+06	87.0226	49.3734	1.0000

BLOCK: COMP2 MODEL: COMPR

INLET STREAM: CO26COLD
OUTLET STREAM: CO218HOT
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	1585.52	1585.52	0.00000
MASS(LB/HR)	69778.5	69778.5	0.00000
ENTHALPY(BTU/HR)	-0.267608E+09	-0.264482E+09	-0.116815E-01

U-O-S BLOCK SECTION

BLOCK: COMP2 MODEL: COMPR (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	69778.5	LB/HR
PRODUCT STREAMS CO2E	69778.5	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

POLYTROPIC COMPRESSOR USING ASME METHOD

PRESSURE RATIO	3.00000
POLYTROPIC EFFICIENCY	0.75000
MECHANICAL EFFICIENCY	1.00000

*** RESULTS ***

```
     INDICATED  HORSEPOWER REQUIREMENT  HP                1,228.59
     BRAKE      HORSEPOWER REQUIREMENT  HP                1,228.59
     NET WORK REQUIRED                  HP                1,228.59
     POWER LOSSES                       HP                    0.0
     ISENTROPIC HORSEPOWER REQUIREMENT  HP                  887.598
     CALCULATED OUTLET PRES  PSIA                           251.049
     CALCULATED OUTLET TEMP  C                              161.806
     EFFICIENCY (POLYTR/ISENTR) USED                        0.75000
     OUTLET VAPOR FRACTION                                  1.00000
     HEAD DEVELOPED,       FT-LBF/LB                     26,146.4
     MECHANICAL EFFICIENCY USED                             1.00000
     INLET HEAT CAPACITY RATIO                              1.27621
     INLET VOLUMETRIC FLOW RATE , CUFT/HR                118,039.
     OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                 53,062.5
     INLET  COMPRESSIBILITY FACTOR                          1.00000
     OUTLET COMPRESSIBILITY FACTOR                          1.00000
     AV. ISENT. VOL. EXPONENT                               1.26106
     AV. ISENT. TEMP EXPONENT                               1.26106
     AV. ACTUAL VOL. EXPONENT                               1.37405
     AV. ACTUAL TEMP EXPONENT                               1.37405
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 23

                              U-O-S BLOCK SECTION

 BLOCK:  COMP2HX  MODEL: HEATX
 ------------------------------
   THIS BLOCK RUNS WITH ASPEN EDR 36.2  WITH ADVANCED METHOD FOR SHELL&TUBE
   HOT SIDE:
   ---------
   INLET STREAM:             CO218HOT
   OUTLET STREAM:            CO218CLD
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
   COLD SIDE:
   ----------
   INLET STREAM:             C2HXCWI
   OUTLET STREAM:            C2HXCWO
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS


     **************************************************************************
     *                                                                        *
     *     A POTENTIAL TUBE VIBRATIEON PROBLEM IS INDICATED                   *
     *                                                                        *
     **************************************************************************


                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            7354.49         7354.49         0.00000
       MASS(LB/HR   )            173708.         173708.         0.00000
       ENTHALPY(BTU/HR  )     -0.971992E+09   -0.971992E+09    0.122644E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             69778.5      LB/HR
     PRODUCT STREAMS CO2E          69778.5      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                30
   CONVERGENCE TOLERANCE                                  0.000100000
```

FLASH SPECS FOR COLD SIDE:

TWO PHASE FLASH	
MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000

U-O-S BLOCK SECTION

BLOCK: COMP2HX MODEL: HEATX (CONTINUED)

SHELL&TUBE INPUT FILE NAME	COMP2HX.EDR
SHELL&TUBE PROGRAM MODE	SIMULATION

HEAT CURVE GENERATION

HOT HEAT CURVE GENERATED BY	ASPEN PLUS
COLD HEAT CURVE GENERATED BY	ASPEN PLUS

*** OVERALL RESULTS ***

STREAMS:

CO218HOT ----->	HOT (SHELL)	-----> CO218CLD
T= 1.6181D+02		T= 4.9766D+01
P= 2.5105D+02		P= 2.4723D+02
V= 1.0000D+00		V= 1.0000D+00
C2HXCWO <-----	COLD (TUBE)	<----- C2HXCWI
T= 4.8890D+01		T= 3.2220D+01
P= 1.3982D+01		P= 1.4504D+01
V= 0.0000D+00		V= 0.0000D+00

UNIT RESULTS:

CALCULATED HEAT DUTY	BTU/HR	3115767.7480
CALCULATED (REQUIRED) AREA	SQFT	390.7362
ACTUAL EXCHANGER AREA	SQFT	391.5787
% OVER (UNDER) DESIGN		0.2156
AVERAGE COEFFICIENT	BTU/HR-SQFT-R	84.7352
UA	BTU/HR-R	33109.0998
LMTD (CORRECTED)	C	52.2812
LMTD CORRECTION FACTOR		1.0206
NUMBER OF SHELLS IN SERIES		1
NUMBER OF SHELLS IN PARALLEL		1
HIGH RHOV2 INDICATION		NO
VIBRATION INDICATION		YES

SHELLSIDE RESULTS:

MEAN SHELL METAL TEMPERATURE	C	89.1159
TOTAL PRESSURE DROP	PSI	3.8196
WINDOW PRESSURE DROP	PSI	1.5173
CROSSFLOW PRESSURE DROP	PSI	1.2518
BULK FILM COEFFICIENT	BTU/HR-SQFT-R	108.9649
WALL FILM COEFFICIENT	BTU/HR-SQFT-R	108.9649
THERMAL RESISTANCE	HR-SQFT-R/BTU	0.0092
MAXIMUM FOULING RESISTANCE	HR-SQFT-R/BTU	0.000013
FOULING RESISTANCE	HR-SQFT-R/BTU	0.0000
CROSSFLOW VELOCITY	FT/SEC	29.5220
WINDOW VELOCITY	FT/SEC	37.7725
MIDPOINT VELOCITY	FT/SEC	33.6472
SHELL ENTRANCE RHOV^2	LB/FT-SQSEC	470.4225
SHELL EXIT RHOV^2	LB/FT-SQSEC	1448.6864
BUNDLE ENTRANCE RHOV^2	LB/FT-SQSEC	621.9015
BUNDLE EXIT RHOV^2	LB/FT-SQSEC	321.7798
FOULING % OF OVERALL RESISTANCE		0.0000

U-O-S BLOCK SECTION

BLOCK: COMP2HX MODEL: HEATX (CONTINUED)

TUBESIDE RESULTS:

MEAN TUBE METAL TEMPERATURE	C	48.7166
TOTAL PRESSURE DROP	PSI	0.5216
BULK FILM COEFFICIENT	BTU/HR-SQFT-R	423.2850
WALL FILM COEFFICIENT	BTU/HR-SQFT-R	423.2850
THERMAL RESISTANCE	HR-SQFT-R/BTU	0.0024
MAXIMUM FOULING RESISTANCE	HR-SQFT-R/BTU	0.000013
FOULING RESISTANCE	HR-SQFT-R/BTU	0.0000
INPUT VELOCITY	FT/SEC	1.6463
OUTLET VELOCITY	FT/SEC	1.6741
FOULING % OF OVERALL RESISTANCE		0.0000
FILM % OF OVERALL RESISTANCE		20.0185
FRICTIONAL PRESSURE DROP	PSI	0.5210

U-O-S BLOCK SECTION

HEATX COLD-TQCU COMP2HX TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: -0.5216 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	14.5038	48.8897	0.0
1.4837+05	14.5038	48.1028	0.0
2.9674+05	14.5038	47.3152	0.0
4.4511+05	14.5038	46.5268	0.0
5.9348+05	14.5038	45.7378	0.0
7.4185+05	14.5038	44.9480	0.0
8.9022+05	14.5038	44.1576	0.0
1.0386+06	14.5038	43.3664	0.0
1.1870+06	14.5038	42.5746	0.0
1.3353+06	14.5038	41.7820	0.0
1.4837+06	14.5038	40.9888	0.0
1.6321+06	14.5038	40.1949	0.0
1.7804+06	14.5038	39.4004	0.0
1.9288+06	14.5038	38.6052	0.0
2.0772+06	14.5038	37.8093	0.0
2.2255+06	14.5038	37.0127	0.0
2.3739+06	14.5038	36.2155	0.0
2.5223+06	14.5038	35.4177	0.0
2.6707+06	14.5038	34.6192	0.0
2.8190+06	14.5038	33.8201	0.0
2.9674+06	14.5038	33.0204	0.0
3.1158+06	14.5038	32.2200	0.0

U-O-S BLOCK SECTION

HEATX HOT-TQCUR COMP2HX TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	251.0494	161.8063	1.0000
1.4837+05	251.0494	156.7138	1.0000
2.9674+05	251.0494	151.6016	1.0000
4.4511+05	251.0494	146.4692	1.0000
5.9348+05	251.0494	141.3160	1.0000
7.4185+05	251.0494	136.1415	1.0000
8.9022+05	251.0494	130.9449	1.0000
1.0386+06	251.0494	125.7256	1.0000
1.1870+06	251.0494	120.4827	1.0000
1.3353+06	251.0494	115.2157	1.0000
1.4837+06	251.0494	109.9236	1.0000
1.6321+06	251.0494	104.6055	1.0000
1.7804+06	251.0494	99.2606	1.0000
1.9288+06	251.0494	93.8878	1.0000
2.0772+06	251.0494	88.4862	1.0000
2.2255+06	251.0494	83.0546	1.0000
2.3739+06	251.0494	77.5918	1.0000
2.5223+06	251.0494	72.0968	1.0000
2.6707+06	251.0494	66.5681	1.0000
2.8190+06	251.0494	61.0043	1.0000
2.9674+06	251.0494	55.4042	1.0000
3.1158+06	251.0494	49.7661	1.0000

BLOCK: COMP3 MODEL: COMPR

INLET STREAM: CO218CLD
OUTLET STREAM: CO225HOT
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	1585.52	1585.52	0.00000
MASS(LB/HR)	69778.5	69778.5	0.00000
ENTHALPY(BTU/HR)	-0.267598E+09	-0.266610E+09	-0.368863E-02

U-O-S BLOCK SECTION

BLOCK: COMP3 MODEL: COMPR (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 69778.5 LB/HR

```
 PRODUCT STREAMS CO2E          69778.5      LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

 POLYTROPIC COMPRESSOR USING ASME METHOD
  OUTLET PRESSURE  PSIA                                  362.594
  POLYTROPIC EFFICIENCY                                  0.75000
  MECHANICAL EFFICIENCY                                  1.00000

                          ***  RESULTS  ***

  INDICATED  HORSEPOWER REQUIREMENT  HP                  387.932
  BRAKE      HORSEPOWER REQUIREMENT  HP                  387.932
  NET WORK REQUIRED                  HP                  387.932
  POWER LOSSES                       HP                    0.0
  ISENTROPIC HORSEPOWER REQUIREMENT  HP                  287.044
  CALCULATED OUTLET TEMP  C                               86.6035
  EFFICIENCY (POLYTR/ISENTR) USED                         0.75000
  OUTLET VAPOR FRACTION                                   1.00000
  HEAD DEVELOPED,       FT-LBF/LB                      8,255.83
  MECHANICAL EFFICIENCY USED                              1.00000
  INLET HEAT CAPACITY RATIO                               1.27604
  INLET VOLUMETRIC FLOW RATE , CUFT/HR                40,002.8
  OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                30,386.8
  INLET  COMPRESSIBILITY FACTOR                           1.00000
  OUTLET COMPRESSIBILITY FACTOR                           1.00000
  AV. ISENT. VOL. EXPONENT                                1.27013
  AV. ISENT. TEMP EXPONENT                                1.27013
  AV. ACTUAL VOL. EXPONENT                                1.39291
  AV. ACTUAL TEMP EXPONENT                                1.39291
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                 04/14/2019  PAGE 29

                            U-O-S BLOCK SECTION

 BLOCK:  COMP3HX  MODEL: HEATX
 ------------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             CO225HOT
   OUTLET STREAM:            CO225CLD
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
   COLD SIDE:
   ----------
   INLET STREAM:             HPFDMX-3
   OUTLET STREAM:            HPFD3-MX
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            11098.7         11098.7          0.00000
       MASS(LB/HR   )            155538.         155538.          0.00000
       ENTHALPY(BTU/HR  )     -0.533927E+09   -0.533927E+09   -0.223269E-15

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            139557.      LB/HR
    PRODUCT STREAMS CO2E         139557.      LB/HR
    NET STREAMS CO2E PRODUCTION  0.00000      LB/HR
    UTILITIES CO2E PRODUCTION    0.00000      LB/HR
    TOTAL CO2E PRODUCTION        0.00000      LB/HR

                          ***  INPUT DATA  ***
```

```
   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  40
   CONVERGENCE TOLERANCE                                    0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  40
   CONVERGENCE TOLERANCE                                    0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     MULTIPLE TUBE PASS SHELL AND TUBE HEAT EXCHANGER
     NUMBER OF SHELLS IN SERIES:                            1.00
     SPECIFIED HOT APPROACH TEMP
     SPECIFIED VALUE               C                      27.7780
     TEMPERATURE TOLERANCE         C                       0.01000
     MINIMUM LMTD CORRECTION FACTOR:                       0.80000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 30

                              U-O-S BLOCK SECTION

 BLOCK:  COMP3HX  MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        PSI                     0.0000
     COLD SIDE PRESSURE DROP        PSI                     0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      BTU/HR-SQFT-R         149.6937
     HOT 2-PHASE   COLD LIQUID      BTU/HR-SQFT-R         149.6937
     HOT VAPOR     COLD LIQUID      BTU/HR-SQFT-R         149.6937
     HOT LIQUID    COLD 2-PHASE     BTU/HR-SQFT-R         149.6937
     HOT 2-PHASE   COLD 2-PHASE     BTU/HR-SQFT-R         149.6937
     HOT VAPOR     COLD 2-PHASE     BTU/HR-SQFT-R         149.6937
     HOT LIQUID    COLD VAPOR       BTU/HR-SQFT-R         149.6937
     HOT 2-PHASE   COLD VAPOR       BTU/HR-SQFT-R         149.6937
     HOT VAPOR     COLD VAPOR       BTU/HR-SQFT-R         149.6937

                          ***  OVERALL RESULTS  ***

   STREAMS:
                    ---------------------------------------
                    |                                     |
   CO225HOT  ----->|                HOT                  |-----> CO225CLD
   T=  8.6604D+01   |                                     |       T=  6.0223D+01
   P=  3.6259D+02   |                                     |       P=  3.6259D+02
   V=  1.0000D+00   |                                     |       V=  1.0000D+00
                    |                                     |
   HPFD3-MX  <-----|                COLD                 |<----- HPFDMX-3
   T=  3.8178D+01   |                                     |       T=  3.2401D+01
   P=  3.6259D+02   |                                     |       P=  3.6259D+02
   V=  1.0000D+00   |                                     |       V=  1.0000D+00
                    ---------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           BTU/HR              711090.6715
     CALCULATED (REQUIRED) AREA     SQFT                   72.4009
     ACTUAL EXCHANGER AREA          SQFT                   72.4009
     PER CENT OVER-DESIGN                                   0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R         149.6937
     UA (DIRTY)                     BTU/HR-R            10837.9505

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                 0.9812
```

```
     LMTD (CORRECTED)              C                        36.4507
     NUMBER OF SHELLS IN SERIES                              1

   PRESSURE DROP:
     HOTSIDE, TOTAL                PSI                      0.0000
     COLDSIDE, TOTAL               PSI                      0.0000
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                              U-O-S BLOCK SECTION

 BLOCK:  COMP3HX  MODEL: HEATX (CONTINUED)

                         ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                   HOT
         ------------------------------------------------------------
         |                                                          |
 HOT IN  |                          VAP                             | HOT OUT
 ------> |                                                          |------>
   86.6  |                                                          |   60.2
         |                                                          |
 COLDOUT |                          VAP                             | COLDIN
 <------ |                                                          |<------
   38.2  |                                                          |   32.4
         |                                                          |
         ------------------------------------------------------------
                                   COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              BTU/HR          SQFT        C         BTU/HR-SQFT-R   BTU/HR-R
     1     711090.671        72.4009      36.4507   149.6937       10837.9505
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 32

                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU COMP3HX  TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

 ----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !   362.5943 !    38.1779 !     1.0000 !
 !  3.3861+04 !   362.5943 !    37.9052 !     1.0000 !
 !  6.7723+04 !   362.5943 !    37.6325 !     1.0000 !
 !  1.0158+05 !   362.5943 !    37.3598 !     1.0000 !
 !  1.3545+05 !   362.5943 !    37.0870 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.6931+05 !   362.5943 !    36.8142 !     1.0000 !
 !  2.0317+05 !   362.5943 !    36.5414 !     1.0000 !
 !  2.3703+05 !   362.5943 !    36.2685 !     1.0000 !
 !  2.7089+05 !   362.5943 !    35.9956 !     1.0000 !
 !  3.0475+05 !   362.5943 !    35.7227 !     1.0000 !
 !------------+------------+------------+------------!
 !  3.3861+05 !   362.5943 !    35.4497 !     1.0000 !
```

```
 !  3.7248+05 !   362.5943 !    35.1767 !     1.0000 !
 !  4.0634+05 !   362.5943 !    34.9037 !     1.0000 !
 !  4.4020+05 !   362.5943 !    34.6306 !     1.0000 !
 !  4.7406+05 !   362.5943 !    34.3575 !     1.0000 !
 !------------+------------+------------+------------!
 !  5.0792+05 !   362.5943 !    34.0844 !     1.0000 !
 !  5.4178+05 !   362.5943 !    33.8112 !     1.0000 !
 !  5.7564+05 !   362.5943 !    33.5380 !     1.0000 !
 !  6.0951+05 !   362.5943 !    33.2648 !     1.0000 !
 !  6.4337+05 !   362.5943 !    32.9915 !     1.0000 !
 !------------+------------+------------+------------!
 !  6.7723+05 !   362.5943 !    32.7182 !     1.0000 !
 !  7.1109+05 !   362.5943 !    32.4449 !     1.0000 !
 ---------------------------------------------------
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 33

                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR COMP3HX  TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

 ---------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !   362.5943 !    86.6035 !     1.0000 !
 !  3.3861+04 !   362.5943 !    85.3642 !     1.0000 !
 !  6.7723+04 !   362.5943 !    84.1232 !     1.0000 !
 !  1.0158+05 !   362.5943 !    82.8807 !     1.0000 !
 !  1.3545+05 !   362.5943 !    81.6365 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.6931+05 !   362.5943 !    80.3907 !     1.0000 !
 !  2.0317+05 !   362.5943 !    79.1433 !     1.0000 !
 !  2.3703+05 !   362.5943 !    77.8942 !     1.0000 !
 !  2.7089+05 !   362.5943 !    76.6434 !     1.0000 !
 !  3.0475+05 !   362.5943 !    75.3909 !     1.0000 !
 !------------+------------+------------+------------!
 !  3.3861+05 !   362.5943 !    74.1367 !     1.0000 !
 !  3.7248+05 !   362.5943 !    72.8807 !     1.0000 !
 !  4.0634+05 !   362.5943 !    71.6230 !     1.0000 !
 !  4.4020+05 !   362.5943 !    70.3636 !     1.0000 !
 !  4.7406+05 !   362.5943 !    69.1024 !     1.0000 !
 !------------+------------+------------+------------!
 !  5.0792+05 !   362.5943 !    67.8394 !     1.0000 !
 !  5.4178+05 !   362.5943 !    66.5746 !     1.0000 !
 !  5.7564+05 !   362.5943 !    65.3080 !     1.0000 !
 !  6.0951+05 !   362.5943 !    64.0395 !     1.0000 !
 !  6.4337+05 !   362.5943 !    62.7692 !     1.0000 !
 !------------+------------+------------+------------!
 !  6.7723+05 !   362.5943 !    61.4970 !     1.0000 !
 !  7.1109+05 !   362.5943 !    60.2229 !     1.0000 !
 ---------------------------------------------------
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 34

                              U-O-S BLOCK SECTION

 BLOCK:  ECONOM1  MODEL: HEATX
 -----------------------------
   HOT SIDE:
```

```
---------
INLET STREAM:             FLUEHOT1
OUTLET STREAM:            FLUECLD1
PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
COLD SIDE:
----------
INLET STREAM:             FEEDCOLD
OUTLET STREAM:            FEEDWARM
PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                    ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)            27211.3         27211.3          0.00000
    MASS(LB/HR   )            233108.         233108.          0.00000
    ENTHALPY(BTU/HR  )     -0.563150E+09   -0.563150E+09    0.211683E-15

                    ***  CO2 EQUIVALENT SUMMARY ***
 FEED STREAMS CO2E             114702.      LB/HR
 PRODUCT STREAMS CO2E          114702.      LB/HR
 NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
 UTILITIES CO2E PRODUCTION     0.00000      LB/HR
 TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***

 FLASH SPECS FOR HOT SIDE:
 TWO    PHASE      FLASH
 MAXIMUM NO. ITERATIONS                                  30
 CONVERGENCE TOLERANCE                                    0.000100000

 FLASH SPECS FOR COLD SIDE:
 TWO    PHASE      FLASH
 MAXIMUM NO. ITERATIONS                                  30
 CONVERGENCE TOLERANCE                                    0.000100000

 FLOW DIRECTION AND SPECIFICATION:
   MULTIPLE TUBE PASS SHELL AND TUBE HEAT EXCHANGER
   NUMBER OF SHELLS IN SERIES:                            1.00
   SPECIFIED COLD OUTLET TEMP
   SPECIFIED VALUE               C                      305.0000
   MINIMUM LMTD CORRECTION FACTOR:                        0.80000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                04/14/2019  PAGE 35

                            U-O-S BLOCK SECTION

 BLOCK:  ECONOM1  MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        PSI                   0.0000
     COLD SIDE PRESSURE DROP        PSI                   0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      BTU/HR-SQFT-R        149.6937
     HOT 2-PHASE   COLD LIQUID      BTU/HR-SQFT-R        149.6937
     HOT VAPOR     COLD LIQUID      BTU/HR-SQFT-R        149.6937
     HOT LIQUID    COLD 2-PHASE     BTU/HR-SQFT-R        149.6937
     HOT 2-PHASE   COLD 2-PHASE     BTU/HR-SQFT-R        149.6937
     HOT VAPOR     COLD 2-PHASE     BTU/HR-SQFT-R        149.6937
     HOT LIQUID    COLD VAPOR       BTU/HR-SQFT-R        149.6937
     HOT 2-PHASE   COLD VAPOR       BTU/HR-SQFT-R        149.6937
     HOT VAPOR     COLD VAPOR       BTU/HR-SQFT-R        149.6937

                        ***  OVERALL RESULTS  ***

   STREAMS:
```

```
                    ---------------------------------------
                    |                                     |
   FLUEHOT1  ----->|                HOT                  |-----> FLUECLD1
   T=  5.0000D+02   |                                     |       T=  8.0345D+01
   P=  3.6259D+02   |                                     |       P=  3.6259D+02
   V=  1.0000D+00   |                                     |       V=  9.4767D-01
                    |                                     |
   FEEDWARM  <-----|                COLD                 |<----- FEEDCOLD
   T=  3.0500D+02   |                                     |       T=  6.3402D+01
   P=  3.6259D+02   |                                     |       P=  3.6259D+02
   V=  1.0000D+00   |                                     |       V=  9.9832D-01
                    ---------------------------------------
```

DUTY AND AREA:

CALCULATED HEAT DUTY	BTU/HR	58859803.4701
CALCULATED (REQUIRED) AREA	SQFT	11676.6823
ACTUAL EXCHANGER AREA	SQFT	11676.6823
PER CENT OVER-DESIGN		0.0000

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY)	BTU/HR-SQFT-R	149.6937
UA (DIRTY)	BTU/HR-R	1747925.2705

LOG-MEAN TEMPERATURE DIFFERENCE:

LMTD CORRECTION FACTOR		0.8541
LMTD (CORRECTED)	C	18.7078
NUMBER OF SHELLS IN SERIES		5

PRESSURE DROP:

HOTSIDE, TOTAL	PSI	0.0000
COLDSIDE, TOTAL	PSI	0.0000

U-O-S BLOCK SECTION

BLOCK: ECONOM1 MODEL: HEATX (CONTINUED)

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

HOT

HOT IN	VAP	COND	COND	HOT OUT
500.0	116.2	85.8		80.3
COLDOUT	VAP	VAP	BOIL	COLDIN
305.0	114.2	67.1		63.4

COLD

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY BTU/HR	AREA SQFT	LMTD C	AVERAGE U BTU/HR-SQFT-R	UA BTU/HR-R
1	46251479.270	4785.5039	35.8692	149.6937	716359.5728
2	11206105.354	6549.1760	6.3503	149.6937	980370.1043
3	1402218.846	342.0024	15.2164	149.6937	51195.5934

U-O-S BLOCK SECTION

HEATX COLD-TQCU ECONOM1 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	362.5943	305.0000	1.0000
2.8028+06	362.5943	293.5664	1.0000
5.6057+06	362.5943	282.1188	1.0000
8.4085+06	362.5943	270.6571	1.0000
1.1211+07	362.5943	259.1810	1.0000
1.4014+07	362.5943	247.6903	1.0000
1.6817+07	362.5943	236.1846	1.0000
1.9620+07	362.5943	224.6634	1.0000
2.2423+07	362.5943	213.1261	1.0000
2.5226+07	362.5943	201.5719	1.0000
2.8028+07	362.5943	189.9999	1.0000
3.0831+07	362.5943	178.4092	1.0000
3.3634+07	362.5943	166.7985	1.0000
3.6437+07	362.5943	155.1663	1.0000
3.9240+07	362.5943	143.5112	1.0000
4.2043+07	362.5943	131.8313	1.0000
4.4846+07	362.5943	120.1246	1.0000
4.6251+07	362.5943	114.2417	1.0000
4.7648+07	362.5943	108.3889	1.0000
5.0451+07	362.5943	96.6215	1.0000
5.3254+07	362.5943	84.8199	1.0000
5.6057+07	362.5943	72.9811	1.0000
5.7458+07	362.5943	67.0500	DEW>1.0000
5.8860+07	362.5943	63.4017	0.9983

U-O-S BLOCK SECTION

HEATX HOT-TQCUR ECONOM1 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	362.5943	500.0000	1.0000
2.8028+06	362.5943	477.2100	1.0000
5.6057+06	362.5943	454.3519	1.0000
8.4085+06	362.5943	431.4278	1.0000
1.1211+07	362.5943	408.4401	1.0000

```
 !------------+------------+------------+------------!
 !  1.4014+07 !   362.5943 !   385.3910 !     1.0000 !
 !  1.6817+07 !   362.5943 !   362.2828 !     1.0000 !
 !  1.9620+07 !   362.5943 !   339.1177 !     1.0000 !
 !  2.2423+07 !   362.5943 !   315.8974 !     1.0000 !
 !  2.5226+07 !   362.5943 !   292.6234 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.8028+07 !   362.5943 !   269.2964 !     1.0000 !
 !  3.0831+07 !   362.5943 !   245.9165 !     1.0000 !
 !  3.3634+07 !   362.5943 !   222.4824 !     1.0000 !
 !  3.6437+07 !   362.5943 !   198.9915 !     1.0000 !
 !  3.9240+07 !   362.5943 !   175.4397 !     1.0000 !
 !------------+------------+------------+------------!
 !  4.2043+07 !   362.5943 !   151.8207 !     1.0000 !
 !  4.4846+07 !   362.5943 !   128.1260 !     1.0000 !
 !  4.6251+07 !   362.5943 !   116.2088 ! DEW>1.0000 !
 !  4.7648+07 !   362.5943 !   113.3045 !     0.9932 !
 !  5.0451+07 !   362.5943 !   106.8642 !     0.9801 !
 !------------+------------+------------+------------!
 !  5.3254+07 !   362.5943 !    99.4279 !     0.9681 !
 !  5.6057+07 !   362.5943 !    90.7142 !     0.9571 !
 !  5.7458+07 !   362.5943 !    85.7673 !     0.9522 !
 !  5.8860+07 !   362.5943 !    80.3451 !     0.9477 !
 ----------------------------------------------------
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 39

                              U-O-S BLOCK SECTION

 BLOCK:  ECONOM2  MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             FLUEHOT2
   OUTLET STREAM:            FLUECLD2
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
   COLD SIDE:
   ----------
   INLET STREAM:             FEEDWARM
   OUTLET STREAM:            FEEDHOT
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            27211.1         27211.3       -0.654900E-05
       MASS(LB/HR   )            233106.         233108.       -0.596669E-05
       ENTHALPY(BTU/HR  )     -0.504291E+09   -0.504292E+09    0.295113E-05

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             114702.      LB/HR
    PRODUCT STREAMS CO2E          114702.      LB/HR
    NET STREAMS CO2E PRODUCTION -0.427658E-01  LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION       -0.427658E-01  LB/HR

                           ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
```

```
  FLOW DIRECTION AND SPECIFICATION:
    MULTIPLE TUBE PASS SHELL AND TUBE HEAT EXCHANGER
    NUMBER OF SHELLS IN SERIES:                          1.00
    SPECIFIED HOT APPROACH TEMP
    SPECIFIED VALUE               C                     27.7780
    TEMPERATURE TOLERANCE         C                      0.01000
    MINIMUM LMTD CORRECTION FACTOR:                      0.80000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                04/14/2019  PAGE 40

                            U-O-S BLOCK SECTION

 BLOCK:  ECONOM2  MODEL: HEATX (CONTINUED)

  PRESSURE SPECIFICATION:
    HOT  SIDE PRESSURE DROP       PSI                    0.0000
    COLD SIDE PRESSURE DROP       PSI                    0.0000

  HEAT TRANSFER COEFFICIENT SPECIFICATION:
    HOT LIQUID    COLD LIQUID     BTU/HR-SQFT-R        149.6937
    HOT 2-PHASE   COLD LIQUID     BTU/HR-SQFT-R        149.6937
    HOT VAPOR     COLD LIQUID     BTU/HR-SQFT-R        149.6937
    HOT LIQUID    COLD 2-PHASE    BTU/HR-SQFT-R        149.6937
    HOT 2-PHASE   COLD 2-PHASE    BTU/HR-SQFT-R        149.6937
    HOT VAPOR     COLD 2-PHASE    BTU/HR-SQFT-R        149.6937
    HOT LIQUID    COLD VAPOR      BTU/HR-SQFT-R        149.6937
    HOT 2-PHASE   COLD VAPOR      BTU/HR-SQFT-R        149.6937
    HOT VAPOR     COLD VAPOR      BTU/HR-SQFT-R        149.6937

                         ***  OVERALL RESULTS  ***

  STREAMS:
                  ---------------------------------------
                  |                                     |
  FLUEHOT2  ----->|               HOT                   |-----> FLUECLD2
  T=  5.0000D+02  |                                     |       T=  3.3278D+02
  P=  3.6259D+02  |                                     |       P=  3.6259D+02
  V=  1.0000D+00  |                                     |       V=  1.0000D+00
                  |                                     |
  FEEDHOT   <-----|               COLD                  |<----- FEEDWARM
  T=  3.8774D+02  |                                     |       T=  3.0500D+02
  P=  3.6259D+02  |                                     |       P=  3.6259D+02
  V=  1.0000D+00  |                                     |       V=  1.0000D+00
                  ---------------------------------------

  DUTY AND AREA:
    CALCULATED HEAT DUTY          BTU/HR          20385457.0030
    CALCULATED (REQUIRED) AREA    SQFT               1545.8722
    ACTUAL EXCHANGER AREA         SQFT               1545.8722
    PER CENT OVER-DESIGN                                0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)   BTU/HR-SQFT-R        149.6937
    UA (DIRTY)                    BTU/HR-R          231407.2621

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                              0.8090
    LMTD (CORRECTED)              C                    48.9408
    NUMBER OF SHELLS IN SERIES                          2

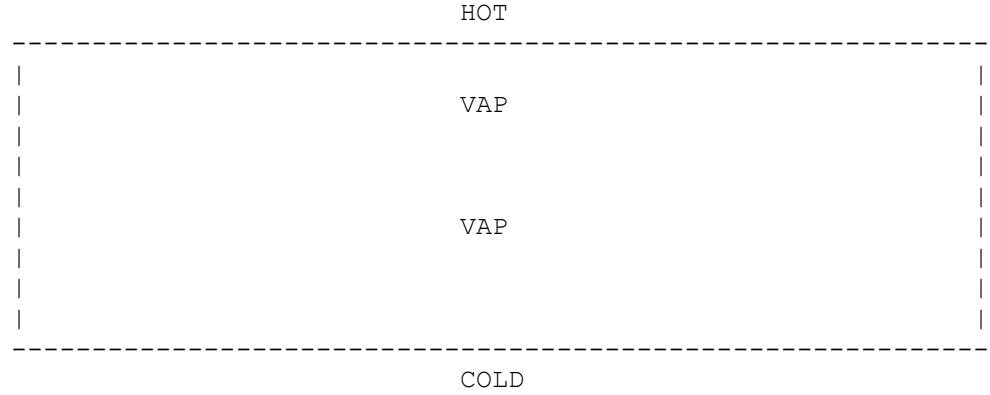
  PRESSURE DROP:
    HOTSIDE, TOTAL                PSI                   0.0000
    COLDSIDE, TOTAL               PSI                   0.0000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                04/14/2019  PAGE 41

                            U-O-S BLOCK SECTION
```

BLOCK: ECONOM2 MODEL: HEATX (CONTINUED)

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:



ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY BTU/HR	AREA SQFT	LMTD C	AVERAGE U BTU/HR-SQFT-R	UA BTU/HR-R
1	20385457.003	1545.8722	48.9408	149.6937	231407.2621

U-O-S BLOCK SECTION

HEATX COLD-TQCU ECONOM2 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY BTU/HR	PRES PSIA	TEMP C	VFRAC
0.0	362.5943	387.7360	1.0000
9.7074+05	362.5943	383.8133	1.0000
1.9415+06	362.5943	379.8888	1.0000
2.9122+06	362.5943	375.9626	1.0000
3.8829+06	362.5943	372.0347	1.0000
4.8537+06	362.5943	368.1050	1.0000
5.8244+06	362.5943	364.1736	1.0000
6.7952+06	362.5943	360.2405	1.0000
7.7659+06	362.5943	356.3057	1.0000
8.7366+06	362.5943	352.3692	1.0000
9.7074+06	362.5943	348.4310	1.0000
1.0678+07	362.5943	344.4911	1.0000
1.1649+07	362.5943	340.5495	1.0000
1.2620+07	362.5943	336.6062	1.0000
1.3590+07	362.5943	332.6613	1.0000
1.4561+07	362.5943	328.7147	1.0000
1.5532+07	362.5943	324.7664	1.0000
1.6503+07	362.5943	320.8164	1.0000
1.7473+07	362.5943	316.8648	1.0000

```
 !  1.8444+07 !   362.5943 !   312.9115 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.9415+07 !   362.5943 !   308.9566 !     1.0000 !
 !  2.0385+07 !   362.5943 !   304.9999 !     1.0000 !
 ----------------------------------------------------
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 43

                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR ECONOM2  TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

 ----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !   362.5943 !   500.0000 !     1.0000 !
 !  9.7074+05 !   362.5943 !   492.1146 !     1.0000 !
 !  1.9415+06 !   362.5943 !   484.2209 !     1.0000 !
 !  2.9122+06 !   362.5943 !   476.3189 !     1.0000 !
 !  3.8829+06 !   362.5943 !   468.4088 !     1.0000 !
 !------------+------------+------------+------------!
 !  4.8537+06 !   362.5943 !   460.4906 !     1.0000 !
 !  5.8244+06 !   362.5943 !   452.5645 !     1.0000 !
 !  6.7952+06 !   362.5943 !   444.6304 !     1.0000 !
 !  7.7659+06 !   362.5943 !   436.6886 !     1.0000 !
 !  8.7366+06 !   362.5943 !   428.7390 !     1.0000 !
 !------------+------------+------------+------------!
 !  9.7074+06 !   362.5943 !   420.7818 !     1.0000 !
 !  1.0678+07 !   362.5943 !   412.8172 !     1.0000 !
 !  1.1649+07 !   362.5943 !   404.8451 !     1.0000 !
 !  1.2620+07 !   362.5943 !   396.8656 !     1.0000 !
 !  1.3590+07 !   362.5943 !   388.8790 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.4561+07 !   362.5943 !   380.8852 !     1.0000 !
 !  1.5532+07 !   362.5943 !   372.8844 !     1.0000 !
 !  1.6503+07 !   362.5943 !   364.8767 !     1.0000 !
 !  1.7473+07 !   362.5943 !   356.8621 !     1.0000 !
 !  1.8444+07 !   362.5943 !   348.8407 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.9415+07 !   362.5943 !   340.8126 !     1.0000 !
 !  2.0385+07 !   362.5943 !   332.7779 !     1.0000 !
 ----------------------------------------------------

 BLOCK:  FEEDHEAT MODEL: HEATER
 ------------------------------
   INLET STREAM:          FEEDHOT
   OUTLET STREAM:         WGSFEED
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT        RELATIVE DIFF.
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 44

                              U-O-S BLOCK SECTION

 BLOCK:  FEEDHEAT MODEL: HEATER (CONTINUED)
    TOTAL BALANCE
       MOLE(LBMOL/HR)            18141.0         18141.0         0.00000
```

```
        MASS(LB/HR   )            155406.         155406.         0.00000
        ENTHALPY(BTU/HR  )      -0.337622E+09   -0.292568E+09   -0.133444

                        ***  CO2 EQUIVALENT SUMMARY ***
      FEED STREAMS CO2E             92170.3      LB/HR
      PRODUCT STREAMS CO2E          92170.3      LB/HR
      NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
      UTILITIES CO2E PRODUCTION     0.00000      LB/HR
      TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***
    TWO    PHASE  TP  FLASH
    SPECIFIED TEMPERATURE               C                      567.720
    PRESSURE DROP                       PSI                      0.0
    MAXIMUM NO. ITERATIONS                                      30
    CONVERGENCE TOLERANCE                                        0.000100000



                              ***  RESULTS  ***
    OUTLET TEMPERATURE    C                                    567.72
    OUTLET PRESSURE       PSIA                                 362.59
    HEAT DUTY             BTU/HR                             0.45054E+08
    OUTLET VAPOR FRACTION                                      1.0000


    V-L PHASE EQUILIBRIUM :

       COMP             F(I)          X(I)          Y(I)          K(I)
       CO2             0.11545       0.20836       0.11545       227.29
       CO              0.58896E-01   0.12114       0.58896E-01   199.44
       H2              0.81493       0.57936       0.81493       577.01
       WATER           0.10729E-01   0.91144E-01   0.10729E-01   48.288

  BLOCK:  FEEDMIX  MODEL: MIXER
  ------------------------------
    INLET STREAMS:         H2IN        CO225CLD
    OUTLET STREAM:         HPFDMX-3
    PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 45

                               U-O-S BLOCK SECTION

  BLOCK:  FEEDMIX  MODEL: MIXER (CONTINUED)

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
     TOTAL BALANCE
        MOLE(LBMOL/HR)            9513.13         9513.13         0.00000
        MASS(LB/HR   )            85759.6         85759.6         0.00000
        ENTHALPY(BTU/HR  )      -0.267322E+09   -0.267316E+09   -0.205355E-04

                        ***  CO2 EQUIVALENT SUMMARY ***
      FEED STREAMS CO2E             69778.5      LB/HR
      PRODUCT STREAMS CO2E          69778.5      LB/HR
      NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
      UTILITIES CO2E PRODUCTION     0.00000      LB/HR
      TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***
    TWO    PHASE      FLASH
    MAXIMUM NO. ITERATIONS                                     30
    CONVERGENCE TOLERANCE                                       0.000100000
    OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES
```

```
 BLOCK:  FLUECOMP MODEL: COMPR
 ------------------------------
   INLET STREAM:          FLURC25
   OUTLET STREAM:         FLURC255
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            8627.78         8627.78          0.00000
       MASS(LB/HR   )            69646.1         69646.1          0.00000
       ENTHALPY(BTU/HR  )     -0.150558E+09   -0.150262E+09   -0.196541E-02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             22391.9      LB/HR
    PRODUCT STREAMS CO2E          22391.9      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 46

                              U-O-S BLOCK SECTION

 BLOCK:  FLUECOMP MODEL: COMPR (CONTINUED)

                           ***  INPUT DATA  ***

   POLYTROPIC COMPRESSOR USING ASME METHOD
    PRESSURE CHANGE  PSI                                    7.25189
    POLYTROPIC EFFICIENCY                                   0.75000
    MECHANICAL EFFICIENCY                                   1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP                  116.296
    BRAKE      HORSEPOWER REQUIREMENT  HP                  116.296
    NET WORK REQUIRED                  HP                  116.296
    POWER LOSSES                       HP                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP                   87.1410
    CALCULATED OUTLET PRES  PSIA                           365.233
    CALCULATED OUTLET TEMP  C                               86.9922
    EFFICIENCY (POLYTR/ISENTR) USED                          0.75000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       FT-LBF/LB                      2,479.68
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.38661
    INLET VOLUMETRIC FLOW RATE , CUFT/HR                166,421.
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                164,336.
    INLET  COMPRESSIBILITY FACTOR                            1.00000
    OUTLET COMPRESSIBILITY FACTOR                            1.00000
    AV. ISENT. VOL. EXPONENT                                 1.38597
    AV. ISENT. TEMP EXPONENT                                 1.38597
    AV. ACTUAL VOL. EXPONENT                                 1.59055
    AV. ACTUAL TEMP EXPONENT                                 1.59055

 BLOCK:  FLUEMIX  MODEL: MIXER
 ------------------------------
   INLET STREAMS:         FLUECLD1    FLUECLD2
   OUTLET STREAM:         FLU2HX
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 47

                              U-O-S BLOCK SECTION

 BLOCK:  FLUEMIX  MODEL: MIXER (CONTINUED)
```

```
                        ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            18140.8         18140.8          0.00000
       MASS(LB/HR   )            155405.         155405.       -0.187278E-15
       ENTHALPY(BTU/HR  )     -0.371814E+09   -0.371814E+09    0.160308E-15

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             45062.3      LB/HR
    PRODUCT STREAMS CO2E          45062.3      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***
    TWO    PHASE      FLASH
    MAXIMUM NO. ITERATIONS                                    30
    CONVERGENCE TOLERANCE                                      0.000100000
    OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  FLUEPURG MODEL: FSPLIT
 ------------------------------
    INLET STREAM:          FLUEDRY
    OUTLET STREAMS:        SYNTOFT     FLURC25
    PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            17255.6         17255.6          0.00000
       MASS(LB/HR   )            139292.         139292.          0.00000
       ENTHALPY(BTU/HR  )     -0.301117E+09   -0.301117E+09     0.00000

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             44783.7      LB/HR
    PRODUCT STREAMS CO2E          44783.7      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 48

                               U-O-S BLOCK SECTION

 BLOCK:  FLUEPURG MODEL: FSPLIT (CONTINUED)

  FRACTION OF FLOW                STRM=SYNTOFT  FRAC=         0.50000

                             ***  RESULTS  ***

  STREAM= SYNTOFT        SPLIT=          0.50000     KEY=  0    STREAM-ORDER=   1
          FLURC25                        0.50000           0                    2

 BLOCK:  FLUESPLT MODEL: FSPLIT
 ------------------------------
    INLET STREAM:          WGSOUT
    OUTLET STREAMS:        FLUEHOT1    FLUEHOT2
    PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            18141.0         18140.8          0.100214E-04
       MASS(LB/HR   )            155406.         155405.          0.101092E-04
       ENTHALPY(BTU/HR  )     -0.292568E+09   -0.292569E+09     0.230618E-05
```

```
                      ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             45062.3      LB/HR
     PRODUCT STREAMS CO2E          45062.3      LB/HR
     NET STREAMS CO2E PRODUCTION  0.195202E-01  LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION        0.195202E-01  LB/HR

                           ***  INPUT DATA  ***

  FRACTION OF FLOW                 STRM=FLUEHOT1 FRAC=         0.50000

                           ***  RESULTS  ***

  STREAM= FLUEHOT1       SPLIT=          0.50000     KEY=  0    STREAM-ORDER=   1
          FLUEHOT2                       0.50000           0                    2
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/14/2019  PAGE 49

                              U-O-S BLOCK SECTION

 BLOCK:  FLUFLASH MODEL: FLASH2
 ------------------------------
    INLET STREAM:          HX2FLASH
    OUTLET VAPOR STREAM:   FLUEDRY
    OUTLET LIQUID STREAM:  H2O
    PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
     TOTAL BALANCE
        MOLE(LBMOL/HR)            18140.8         18140.8        0.200541E-15
        MASS(LB/HR   )            155405.         155405.        0.374556E-15
        ENTHALPY(BTU/HR  )     -0.419481E+09   -0.408166E+09   -0.269746E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             45062.3      LB/HR
     PRODUCT STREAMS CO2E          45062.3      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
    TWO    PHASE  TP  FLASH
    SPECIFIED TEMPERATURE C                                  84.3204
    PRESSURE DROP         PSI                                 0.0
    MAXIMUM NO. ITERATIONS                                   30
    CONVERGENCE TOLERANCE                                     0.000100000

                            ***  RESULTS  ***
    OUTLET TEMPERATURE    C                                   84.320
    OUTLET PRESSURE       PSIA                                357.98
    HEAT DUTY             BTU/HR                             0.11315E+08
    VAPOR FRACTION                                           0.95120



    V-L PHASE EQUILIBRIUM :

       COMP             F(I)           X(I)           Y(I)           K(I)
       CO2             0.56443E-01    0.71518E-02    0.58971E-01     8.2457
       CO              0.11790        0.21601E-02    0.12384         57.328
       H2              0.75592        0.13596E-02    0.79463         584.45
       WATER           0.69735E-01    0.98933        0.22559E-01    0.22802E-01
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/14/2019  PAGE 50

                              U-O-S BLOCK SECTION
```

```
 BLOCK:  HPMIX    MODEL: MIXER
 ------------------------------
   INLET STREAMS:          HPFD3-MX    FLURC255
   OUTLET STREAM:          FEEDCOLD
   PROPERTY OPTION SET:    NRTL      RENON (NRTL) / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            18140.9         18140.8        0.580670E-05
       MASS(LB/HR   )            155406.         155405.        0.675124E-05
       ENTHALPY(BTU/HR  )      -0.416867E+09   -0.416866E+09   -0.388836E-05

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             92170.4      LB/HR
    PRODUCT STREAMS CO2E          92170.4      LB/HR
    NET STREAMS CO2E PRODUCTION  0.347523E-02  LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION        0.347523E-02  LB/HR

                             ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  HTWGS    MODEL: RGIBBS
 ------------------------------
   INLET STREAM:           WGSFEED
   OUTLET STREAM:          WGSOUT
   PROPERTY OPTION SET:    NRTL      RENON (NRTL) / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                IN          OUT       GENERATION   RELATIVE DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)          18141.0       18141.0      0.140983E-10  0.200539E-15
   MASS(LB/HR   )          155406.       155406.                    -0.318369E-14
   ENTHALPY(BTU/HR  )   -0.292568E+09 -0.292568E+09                  -0.893393E-06
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/14/2019  PAGE 51

                               U-O-S BLOCK SECTION

 BLOCK:  HTWGS    MODEL: RGIBBS (CONTINUED)

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             92170.3      LB/HR
    PRODUCT STREAMS CO2E          45062.3      LB/HR
    NET STREAMS CO2E PRODUCTION  -47108.0      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION        -47108.0      LB/HR

                             ***  INPUT DATA  ***

   EQUILIBRIUM SPECIFICATIONS:
     ONLY CHEMICAL EQUILIBRIUM IS CONSIDERED, THE FLUID PHASE IS VAPOR
     CALCULATED TEMPERATURE    C                                500.00
     TEMPERATURE FOR FREE ENERGY EVALUATION    C                500.00
     SYSTEM PRESSURE DROP  PSI                                  0.0000
     SPECIFIED DUTY        BTU/HR                                 0.0000

   FLUID PHASE SPECIES IN PRODUCT LIST:
     CO2 CO H2 WATER

   ATOM MATRIX:
   ELEMENT      H    C    N    O
```

```
      CO2        0.00 1.00 0.00 2.00
      CO         0.00 1.00 0.00 1.00
      O2         0.00 0.00 0.00 2.00
      N2         0.00 0.00 2.00 0.00
      H2         2.00 0.00 0.00 0.00
      CH4        4.00 1.00 0.00 0.00
      WATER      2.00 0.00 0.00 1.00

   REACTION STOICHIOMETRY:

    REACTION #   1:
     SUBSTREAM MIXED   :
     CO2       -1.00    CO         1.00    H2        -1.00    WATER      1.00

   TEMPERATURE APPROACH SPECIFICATIONS, DEGREES C
     REACTION   1,    0.0000

                           ***  RESULTS  ***
   TEMPERATURE           C                                   500.00
   PRESSURE              PSIA                                362.59
   VAPOR FRACTION                                            1.0000
   NUMBER OF FLUID PHASES                                         1
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                 04/14/2019  PAGE 52

                              U-O-S BLOCK SECTION

 BLOCK:  HTWGS    MODEL: RGIBBS (CONTINUED)

   FLUID PHASE MOLE FRACTIONS:

   PHASE              VAPOR
   OF TYPE            VAPOR
   PHASE FRACTION     1.000000
   PLACED IN STREAM   WGSOUT
     CO2             0.5644211E-01
     CO              0.1179008
     H2              0.7559238
     WATER           0.6973327E-01

   LBMOL/HR           18140.99

   REACTION EQUILIBRIUM CONSTANTS:

     REACTION        EQUILIBRIUM
      NUMBER          CONSTANT
        1            0.19270

 BLOCK:  WGSFLAHX MODEL: HEATX
 ------------------------------
   THIS BLOCK RUNS WITH ASPEN EDR 36.2  WITH ADVANCED METHOD FOR SHELL&TUBE
   HOT SIDE:
   ---------
   INLET STREAM:             FLU2HX
   OUTLET STREAM:            HX2FLASH
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
   COLD SIDE:
   ----------
   INLET STREAM:             FLUECWI
   OUTLET STREAM:            FLUECWO
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS


     **********************************************************************
     *                                                                    *
     *     A POTENTIAL TUBE VIBRATIEON PROBLEM IS INDICATED               *
     *                                                                    *
```

```
     *********************************************************************


                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            106395.         106395.         0.00000
      MASS(LB/HR   )          0.174533E+07    0.174533E+07     0.00000
      ENTHALPY(BTU/HR  )     -0.111954E+11   -0.111954E+11     0.00000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 53

                              U-O-S BLOCK SECTION

 BLOCK:  WGSFLAHX MODEL: HEATX (CONTINUED)

                      ***  CO2 EQUIVALENT SUMMARY ***
   FEED STREAMS CO2E              45062.3      LB/HR
   PRODUCT STREAMS CO2E           45062.3      LB/HR
   NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
   UTILITIES CO2E PRODUCTION     0.00000      LB/HR
   TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

  FLASH SPECS FOR HOT SIDE:
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.000100000

  FLASH SPECS FOR COLD SIDE:
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.000100000

  SHELL&TUBE INPUT FILE NAME

  WGSFLAHX.EDR


  SHELL&TUBE PROGRAM MODE                                       SIMULATION

  HEAT CURVE GENERATION
    HOT  HEAT CURVE GENERATED BY                          ASPEN PLUS
    COLD HEAT CURVE GENERATED BY                          ASPEN PLUS

                          ***  OVERALL RESULTS  ***

  STREAMS:
                  --------------------------------------
                  |                                    |
  FLU2HX    ----->|            HOT  (SHELL)            |-----> HX2FLASH
  T=  1.7222D+02  |                                    |       T=  5.8422D+01
  P=  3.6259D+02  |                                    |       P=  3.5798D+02
  V=  1.0000D+00  |                                    |       V=  9.3621D-01
                  |                                    |
  FLUECWO   <-----|            COLD (TUBE)             |<----- FLUECWI
  T=  4.8890D+01  |                                    |       T=  3.2220D+01
  P=  1.2497D+01  |                                    |       P=  1.4504D+01
  V=  0.0000D+00  |                                    |       V=  0.0000D+00
                  --------------------------------------

  UNIT RESULTS:
    CALCULATED HEAT DUTY           BTU/HR          47667486.1372
    CALCULATED (REQUIRED) AREA     SQFT                1022.6883
    ACTUAL EXCHANGER AREA          SQFT                1025.5069
    % OVER (UNDER) DESIGN                                 0.2756
```

AVERAGE COEFFICIENT	BTU/HR-SQFT-R	447.2877	
UA	BTU/HR-R	457435.9414	
LMTD (CORRECTED)	C	57.8921	
LMTD CORRECTION FACTOR		0.9233	
NUMBER OF SHELLS IN SERIES		1	
NUMBER OF SHELLS IN PARALLEL		1	
HIGH RHOV2 INDICATION			NO
VIBRATION INDICATION			YES

U-O-S BLOCK SECTION

BLOCK: WGSFLAHX MODEL: HEATX (CONTINUED)

SHELLSIDE RESULTS:

MEAN SHELL METAL TEMPERATURE	C	94.4235
TOTAL PRESSURE DROP	PSI	4.6132
WINDOW PRESSURE DROP	PSI	0.4951
CROSSFLOW PRESSURE DROP	PSI	1.4432
BULK FILM COEFFICIENT	BTU/HR-SQFT-R	847.2856
WALL FILM COEFFICIENT	BTU/HR-SQFT-R	847.2856
THERMAL RESISTANCE	HR-SQFT-R/BTU	0.0012
MAXIMUM FOULING RESISTANCE	HR-SQFT-R/BTU	0.000003
FOULING RESISTANCE	HR-SQFT-R/BTU	0.0000
CROSSFLOW VELOCITY	FT/SEC	98.9601
WINDOW VELOCITY	FT/SEC	80.8330
MIDPOINT VELOCITY	FT/SEC	89.8965
SHELL ENTRANCE RHOV^2	LB/FT-SQSEC	746.7545
SHELL EXIT RHOV^2	LB/FT-SQSEC	1518.8425
BUNDLE ENTRANCE RHOV^2	LB/FT-SQSEC	1921.7317
BUNDLE EXIT RHOV^2	LB/FT-SQSEC	1342.8634
FOULING % OF OVERALL RESISTANCE		0.0000
FILM % OF OVERALL RESISTANCE		52.7907
FRICTIONAL PRESSURE DROP	PSI	4.7213

TUBESIDE RESULTS:

MEAN TUBE METAL TEMPERATURE	C	61.8690
TOTAL PRESSURE DROP	PSI	2.0064
BULK FILM COEFFICIENT	BTU/HR-SQFT-R	1260.1862
WALL FILM COEFFICIENT	BTU/HR-SQFT-R	1260.1862
THERMAL RESISTANCE	HR-SQFT-R/BTU	0.0008
MAXIMUM FOULING RESISTANCE	HR-SQFT-R/BTU	0.000003
FOULING RESISTANCE	HR-SQFT-R/BTU	0.0000
INPUT VELOCITY	FT/SEC	6.2861
OUTLET VELOCITY	FT/SEC	6.3921
FOULING % OF OVERALL RESISTANCE		0.0000
FILM % OF OVERALL RESISTANCE		35.4938
FRICTIONAL PRESSURE DROP	PSI	1.9976

U-O-S BLOCK SECTION

HEATX COLD-TQCU WGSFLAHX TQCURV INLET

PRESSURE PROFILE:	CONSTANT2	
PRESSURE DROP:	-2.0064	PSI
PROPERTY OPTION SET:	NRTL	RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	

```
 !     0.0    !    14.5038 !    48.8904 !     0.0    !
 !  2.2699+06 !    14.5038 !    48.1035 !     0.0    !
 !  4.5398+06 !    14.5038 !    47.3158 !     0.0    !
 !  6.8096+06 !    14.5038 !    46.5274 !     0.0    !
 !  9.0795+06 !    14.5038 !    45.7384 !     0.0    !
 !------------+------------+------------+------------!
 !  1.1349+07 !    14.5038 !    44.9486 !     0.0    !
 !  1.3257+07 !    14.5038 !    44.2844 !     0.0    !
 !  1.3619+07 !    14.5038 !    44.1581 !     0.0    !
 !  1.5889+07 !    14.5038 !    43.3669 !     0.0    !
 !  1.8159+07 !    14.5038 !    42.5750 !     0.0    !
 !------------+------------+------------+------------!
 !  2.0429+07 !    14.5038 !    41.7824 !     0.0    !
 !  2.2699+07 !    14.5038 !    40.9892 !     0.0    !
 !  2.4969+07 !    14.5038 !    40.1953 !     0.0    !
 !  2.7239+07 !    14.5038 !    39.4007 !     0.0    !
 !  2.9508+07 !    14.5038 !    38.6054 !     0.0    !
 !------------+------------+------------+------------!
 !  3.1778+07 !    14.5038 !    37.8095 !     0.0    !
 !  3.4048+07 !    14.5038 !    37.0129 !     0.0    !
 !  3.6318+07 !    14.5038 !    36.2157 !     0.0    !
 !  3.8588+07 !    14.5038 !    35.4178 !     0.0    !
 !  4.0858+07 !    14.5038 !    34.6193 !     0.0    !
 !------------+------------+------------+------------!
 !  4.3128+07 !    14.5038 !    33.8202 !     0.0    !
 !  4.5398+07 !    14.5038 !    33.0204 !     0.0    !
 !  4.7667+07 !    14.5038 !    32.2200 !     0.0    !
 ----------------------------------------------------
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 56

                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR WGSFLAHX TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

 ----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !   362.5943 !   172.2153 !     1.0000 !
 !  2.2699+06 !   362.5943 !   162.6560 !     1.0000 !
 !  4.5398+06 !   362.5943 !   153.0850 !     1.0000 !
 !  6.8096+06 !   362.5943 !   143.5017 !     1.0000 !
 !  9.0795+06 !   362.5943 !   133.9055 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.1349+07 !   362.5943 !   124.2955 !     1.0000 !
 !  1.3257+07 !   362.5943 !   116.2097 ! DEW>1.0000 !
 !  1.3619+07 !   362.5943 !   115.8430 !     0.9991 !
 !  1.5889+07 !   362.5943 !   113.4782 !     0.9936 !
 !  1.8159+07 !   362.5943 !   110.9853 !     0.9882 !
 !------------+------------+------------+------------!
 !  2.0429+07 !   362.5943 !   108.3521 !     0.9829 !
 !  2.2699+07 !   362.5943 !   105.5647 !     0.9778 !
 !  2.4969+07 !   362.5943 !   102.6074 !     0.9729 !
 !  2.7239+07 !   362.5943 !    99.4623 !     0.9681 !
 !  2.9508+07 !   362.5943 !    96.1091 !     0.9635 !
 !------------+------------+------------+------------!
 !  3.1778+07 !   362.5943 !    92.5248 !     0.9592 !
 !  3.4048+07 !   362.5943 !    88.6838 !     0.9550 !
```

```
!  3.6318+07 !   362.5943 !    84.5572 !     0.9511 !
!  3.8588+07 !   362.5943 !    80.1137 !     0.9475 !
!  4.0858+07 !   362.5943 !    75.3198 !     0.9442 !
!------------+------------+------------+------------!
!  4.3128+07 !   362.5943 !    70.1412 !     0.9412 !
!  4.5398+07 !   362.5943 !    64.5454 !     0.9385 !
!  4.7667+07 !   362.5943 !    58.5051 !     0.9361 !
 -------------------------------------------------
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 57

                                STREAM SECTION

 C1HXCWI C1HXCWO C2HXCWI C2HXCWO CO218CLD
 ----------------------------------------

 STREAM ID               C1HXCWI    C1HXCWO    C2HXCWI    C2HXCWO    CO218CLD
 FROM :                  ----       COMP1HX    ----       COMP2HX    COMP2HX
 TO   :                  COMP1HX    ----       COMP2HX    ----       COMP3

 SUBSTREAM: MIXED
 PHASE:                  LIQUID     LIQUID     LIQUID     LIQUID     VAPOR
 COMPONENTS: LBMOL/HR
   CO2                    0.0        0.0        0.0        0.0     1585.5221
   CO                     0.0        0.0        0.0        0.0        0.0
   O2                     0.0        0.0        0.0        0.0        0.0
   N2                     0.0        0.0        0.0        0.0        0.0
   H2                     0.0        0.0        0.0        0.0        0.0
   CH4                    0.0        0.0        0.0        0.0        0.0
   WATER               6011.6704  6011.6704  5768.9646  5768.9646     0.0
 TOTAL FLOW:
   LBMOL/HR            6011.6704  6011.6704  5768.9646  5768.9646  1585.5221
   LB/HR               1.0830+05  1.0830+05  1.0393+05  1.0393+05  6.9779+04
   CUFT/HR             1757.7424  1787.3713  1686.7781  1715.2102  4.0003+04
 STATE VARIABLES:
   TEMP   C              32.2200    48.8900    32.2200    48.8897    49.7661
   PRES   PSIA           14.5038    14.0870    14.5038    13.9822   247.2299
   VFRAC                  0.0        0.0        0.0        0.0        1.0000
   LFRAC                  1.0000     1.0000     1.0000     1.0000     0.0
   SFRAC                  0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   BTU/LBMOL          -1.2264+05 -1.2210+05 -1.2264+05 -1.2210+05 -1.6878+05
   BTU/LB             -6807.6002 -6777.6200 -6807.6002 -6777.6206 -3834.9565
   BTU/HR             -7.3728+08 -7.3403+08 -7.0751+08 -7.0439+08 -2.6760+08
 ENTROPY:
   BTU/LBMOL-R          -38.5414   -37.5886   -38.5414   -37.5886    -4.1951
   BTU/LB-R              -2.1394    -2.0865    -2.1394    -2.0865 -9.5321-02
 DENSITY:
   LBMOL/CUFT             3.4201     3.3634     3.4201     3.3634  3.9635-02
   LB/CUFT               61.6142    60.5929    61.6142    60.5929     1.7443
 AVG MW                  18.0153    18.0153    18.0153    18.0153    44.0098
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 58

                                STREAM SECTION

 CO218HOT CO225CLD CO225HOT CO22BAR CO26COLD
 -------------------------------------------

 STREAM ID               CO218HOT   CO225CLD   CO225HOT   CO22BAR    CO26COLD
 FROM :                  COMP2      COMP3HX    COMP3      ----       COMP1HX
 TO   :                  COMP2HX    FEEDMIX    COMP3HX    COMP1      COMP2

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      VAPOR      VAPOR      VAPOR      VAPOR
 COMPONENTS: LBMOL/HR
   CO2                1585.5221  1585.5221  1585.5221  1585.5221  1585.5221
   CO                    0.0        0.0        0.0        0.0        0.0
```

	O2	0.0	0.0	0.0	0.0	0.0
	N2	0.0	0.0	0.0	0.0	0.0
	H2	0.0	0.0	0.0	0.0	0.0
	CH4	0.0	0.0	0.0	0.0	0.0
	WATER	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:						
	LBMOL/HR	1585.5221	1585.5221	1585.5221	1585.5221	1585.5221
	LB/HR	6.9779+04	6.9779+04	6.9779+04	6.9779+04	6.9779+04
	CUFT/HR	5.3063+04	2.8159+04	3.0387+04	3.4413+05	1.1804+05
STATE VARIABLES:						
	TEMP C	161.8063	60.2229	86.6035	52.7853	49.3734
	PRES PSIA	251.0494	362.5943	362.5943	29.0075	83.6831
	VFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
	LFRAC	0.0	0.0	0.0	0.0	0.0
	SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:						
	BTU/LBMOL	-1.6681+05	-1.6860+05	-1.6815+05	-1.6873+05	-1.6878+05
	BTU/LB	-3790.3042	-3831.0014	-3820.8107	-3833.8196	-3835.1040
	BTU/HR	-2.6448+08	-2.6732+08	-2.6661+08	-2.6752+08	-2.6761+08
ENTROPY:						
	BTU/LBMOL-R	-1.3308	-4.6609	-3.9417	0.1458	-2.0550
	BTU/LB-R	-3.0239-02	-0.1059	-8.9564-02	3.3131-03	-4.6694-02
DENSITY:						
	LBMOL/CUFT	2.9880-02	5.6307-02	5.2178-02	4.6073-03	1.3432-02
	LB/CUFT	1.3150	2.4781	2.2963	0.2028	0.5911
AVG MW		44.0098	44.0098	44.0098	44.0098	44.0098

STREAM SECTION

CO26HOT FEEDCOLD FEEDHOT FEEDWARM FLU2HX

STREAM ID	CO26HOT	FEEDCOLD	FEEDHOT	FEEDWARM	FLU2HX
FROM :	COMP1	HPMIX	ECONOM2	ECONOM1	FLUEMIX
TO :	COMP1HX	ECONOM1	FEEDHEAT	ECONOM2	WGSFLAHX
CONV. MAX. REL. ERR:	0.0	2.8862-05	0.0	-3.6255-05	0.0
SUBSTREAM: MIXED					
PHASE:	VAPOR	MIXED	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
CO2	1585.5221	2094.3147	2094.3138	2094.3147	1023.9161
CO	0.0	1068.4013	1068.4400	1068.4013	2138.7764
O2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
H2	0.0	1.4783+04	1.4784+04	1.4783+04	1.3713+04
CH4	0.0	0.0	0.0	0.0	0.0
WATER	0.0	194.6285	194.6325	194.6285	1265.0543
TOTAL FLOW:					
LBMOL/HR	1585.5221	1.8141+04	1.8141+04	1.8141+04	1.8141+04
LB/HR	6.9779+04	1.5540+05	1.5541+05	1.5540+05	1.5540+05
CUFT/HR	1.5453+05	3.2471+05	6.3870+05	5.5873+05	4.3041+05
STATE VARIABLES:					
TEMP C	165.9401	63.4019	387.7360	305.0000	172.2153
PRES PSIA	87.0226	362.5943	362.5943	362.5943	362.5943
VFRAC	1.0000	0.9983	1.0000	1.0000	1.0000
LFRAC	0.0	1.6785-03	0.0	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.6673+05	-2.2979+04	-1.8611+04	-1.9735+04	-2.0496+04
BTU/LB	-3788.5723	-2682.4525	-2172.5143	-2303.7007	-2392.5557
BTU/HR	-2.6436+08	-4.1687+08	-3.3762+08	-3.5801+08	-3.7181+08
ENTROPY:					
BTU/LBMOL-R	0.8700	-3.0706	1.9805	0.9713	-5.8681-02
BTU/LB-R	1.9769-02	-0.3584	0.2312	0.1134	-6.8500-03

DENSITY:						
LBMOL/CUFT		1.0260-02	5.5867-02	2.8403-02	3.2468-02	4.2148-02
LB/CUFT		0.4515	0.4786	0.2433	0.2781	0.3611
AVG MW		44.0098	8.5666	8.5666	8.5666	8.5666

STREAM SECTION

FLUECLD1 FLUECLD2 FLUECWI FLUECWO FLUEDRY

STREAM ID	FLUECLD1	FLUECLD2	FLUECWI	FLUECWO	FLUEDRY
FROM :	ECONOM1	ECONOM2	----	WGSFLAHX	FLUFLASH
TO :	FLUEMIX	FLUEMIX	WGSFLAHX	----	FLUEPURG
SUBSTREAM: MIXED					
PHASE:	MIXED	VAPOR	LIQUID	LIQUID	VAPOR
COMPONENTS: LBMOL/HR					
CO2	511.9578	511.9583	0.0	0.0	1017.5851
CO	1069.4190	1069.3574	0.0	0.0	2136.8642
O2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
H2	6856.6027	6856.4584	0.0	0.0	1.3712+04
CH4	0.0	0.0	0.0	0.0	0.0
WATER	632.5153	632.5390	8.8254+04	8.8254+04	389.2617
TOTAL FLOW:					
LBMOL/HR	9070.4949	9070.3131	8.8254+04	8.8254+04	1.7256+04
LB/HR	7.7703+04	7.7701+04	1.5899+06	1.5899+06	1.3929+05
CUFT/HR	1.6202+05	2.9279+05	2.5805+04	2.6240+04	3.3284+05
STATE VARIABLES:					
TEMP C	80.3451	332.7779	32.2200	48.8904	84.3204
PRES PSIA	362.5943	362.5943	14.5038	12.4974	357.9812
VFRAC	0.9477	1.0000	0.0	0.0	1.0000
LFRAC	5.2328-02	0.0	1.0000	1.0000	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-2.2617+04	-1.8375+04	-1.2264+05	-1.2210+05	-1.7450+04
BTU/LB	-2640.1001	-2145.0063	-6807.6002	-6777.6192	-2161.7607
BTU/HR	-2.0514+08	-1.6667+08	-1.0824+10	-1.0776+10	-3.0112+08
ENTROPY:					
BTU/LBMOL-R	-3.1006	2.1995	-38.5414	-37.5886	-1.2360
BTU/LB-R	-0.3619	0.2568	-2.1394	-2.0865	-0.1531
DENSITY:					
LBMOL/CUFT	5.5983-02	3.0979-02	3.4201	3.3634	5.1843-02
LB/CUFT	0.4796	0.2654	61.6142	60.5928	0.4185
AVG MW	8.5666	8.5666	18.0153	18.0153	8.0723

STREAM SECTION

FLUEHOT1 FLUEHOT2 FLURC25 FLURC255 H2IN

STREAM ID	FLUEHOT1	FLUEHOT2	FLURC25	FLURC255	H2IN
FROM :	FLUESPLT	FLUESPLT	FLUEPURG	FLUECOMP	----
TO :	ECONOM1	ECONOM2	FLUECOMP	HPMIX	FEEDMIX
CONV. MAX. REL. ERR:	0.0	5.7643-05	0.0	0.0	0.0
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
CO2	511.9578	511.9583	508.7925	508.7925	0.0
CO	1069.4190	1069.3574	1068.4321	1068.4321	0.0
O2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0

H2	6856.6027	6856.4584	6855.9287	6855.9287	7927.6105	
CH4	0.0	0.0	0.0	0.0	0.0	
WATER	632.5153	632.5390	194.6309	194.6309	0.0	
TOTAL FLOW:						
LBMOL/HR	9070.4949	9070.3131	8627.7842	8627.7842	7927.6105	
LB/HR	7.7703+04	7.7701+04	6.9646+04	6.9646+04	1.5981+04	
CUFT/HR	3.7360+05	3.7359+05	1.6642+05	1.6434+05	1.2592+05	
STATE VARIABLES:						
TEMP C	500.0000	500.0000	84.3204	86.9922	25.0000	
PRES PSIA	362.5943	362.5943	357.9812	365.2330	362.5943	
VFRAC	1.0000	1.0000	1.0000	1.0000	1.0000	
LFRAC	0.0	0.0	0.0	0.0	0.0	
SFRAC	0.0	0.0	0.0	0.0	0.0	
ENTHALPY:						
BTU/LBMOL	-1.6127+04	-1.6128+04	-1.7450+04	-1.7416+04	1.6016-12	
BTU/LB	-1882.6034	-1882.6501	-2161.7607	-2157.5120	7.9449-13	
BTU/HR	-1.4628+08	-1.4628+08	-1.5056+08	-1.5026+08	1.2697-08	
ENTROPY:						
BTU/LBMOL-R	4.0187	4.0187	-1.2360	-1.2227	-6.3660	
BTU/LB-R	0.4691	0.4691	-0.1531	-0.1515	-3.1579	
DENSITY:						
LBMOL/CUFT	2.4279-02	2.4279-02	5.1843-02	5.2501-02	6.2959-02	
LB/CUFT	0.2080	0.2080	0.4185	0.4238	0.1269	
AVG MW	8.5666	8.5666	8.0723	8.0723	2.0159	

STREAM SECTION

H2O HPFD3-MX HPFDMX-3 HX2FLASH SYNTOFT

STREAM ID	H2O	HPFD3-MX	HPFDMX-3	HX2FLASH	SYNTOFT
FROM :	FLUFLASH	COMP3HX	FEEDMIX	WGSFLAHX	FLUEPURG
TO :	----	HPMIX	COMP3HX	FLUFLASH	----
CONV. MAX. REL. ERR:	0.0	0.0	-2.0536-05	0.0	0.0
SUBSTREAM: MIXED					
PHASE:	LIQUID	VAPOR	VAPOR	MIXED	VAPOR
COMPONENTS: LBMOL/HR					
CO2	6.3310	1585.5221	1585.5221	1023.9161	508.7925
CO	1.9122	0.0	0.0	2138.7764	1068.4321
O2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
H2	1.2036	7927.6105	7927.6105	1.3713+04	6855.9287
CH4	0.0	0.0	0.0	0.0	0.0
WATER	875.7926	0.0	0.0	1265.0543	194.6309
TOTAL FLOW:					
LBMOL/HR	885.2395	9513.1326	9513.1326	1.8141+04	8627.7842
LB/HR	1.6112+04	8.5760+04	8.5760+04	1.5540+05	6.9646+04
CUFT/HR	276.6218	1.5778+05	1.5485+05	3.0421+05	1.6642+05
STATE VARIABLES:					
TEMP C	84.3204	38.1779	32.4006	58.4224	84.3204
PRES PSIA	357.9812	362.5943	362.5943	357.9812	357.9812
VFRAC	0.0	1.0000	1.0000	0.9362	1.0000
LFRAC	1.0000	0.0	0.0	6.3792-02	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.2093+05	-2.8025+04	-2.8100+04	-2.3124+04	-1.7450+04
BTU/LB	-6643.9824	-3108.7473	-3117.0389	-2699.2874	-2161.7607
BTU/HR	-1.0705+08	-2.6660+08	-2.6732+08	-4.1948+08	-1.5056+08
ENTROPY:					
BTU/LBMOL-R	-35.2128	-5.0437	-5.1794	-3.8966	-1.2360
BTU/LB-R	-1.9347	-0.5595	-0.5745	-0.4549	-0.1531
DENSITY:					
LBMOL/CUFT	3.2002	6.0294-02	6.1434-02	5.9632-02	5.1843-02

```
  LB/CUFT              58.2465     0.5435     0.5538     0.5108     0.4185
AVG MW                 18.2010     9.0149     9.0149     8.5666     8.0723
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                                STREAM SECTION

WGSFEED WGSOUT
--------------

STREAM ID              WGSFEED    WGSOUT
FROM :                 FEEDHEAT   HTWGS
TO   :                 HTWGS      FLUESPLT

SUBSTREAM: MIXED
PHASE:                 VAPOR      VAPOR
COMPONENTS: LBMOL/HR
  CO2                2094.3138  1023.9157
  CO                 1068.4400  2138.8381
  O2                    0.0        0.0
  N2                    0.0        0.0
  H2                 1.4784+04  1.3713+04
  CH4                   0.0        0.0
  WATER               194.6325  1265.0306
TOTAL FLOW:
  LBMOL/HR           1.8141+04  1.8141+04
  LB/HR              1.5541+05  1.5541+05
  CUFT/HR            8.1264+05  7.4719+05
STATE VARIABLES:
  TEMP   C            567.7201   500.0000
  PRES   PSIA         362.5943   362.5943
  VFRAC                 1.0000     1.0000
  LFRAC                 0.0        0.0
  SFRAC                 0.0        0.0
ENTHALPY:
  BTU/LBMOL         -1.6127+04 -1.6127+04
  BTU/LB            -1882.6051 -1882.6034
  BTU/HR            -2.9257+08 -2.9257+08
ENTROPY:
  BTU/LBMOL-R           3.8260     4.0187
  BTU/LB-R              0.4466     0.4691
DENSITY:
  LBMOL/CUFT         2.2324-02  2.4279-02
  LB/CUFT               0.1912     0.2080
AVG MW                  8.5666     8.5666
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                            PROBLEM STATUS SECTION

BLOCK STATUS
------------

*****************************************************************************
*                                                                           *
* Calculations were completed with warnings                                 *
*                                                                           *
* The following Unit Operation blocks were                                  *
* completed with warnings:                                                  *
*   COMP1HX   COMP2HX   WGSFLAHX                                            *
*                                                                           *
* All streams were flashed normally                                         *
*                                                                           *
* All Convergence blocks were completed normally                            *
*                                                                           *
* All Sensitivity blocks were completed normally                            *
*                                                                           *
* All Calculator blocks were completed normally                             *
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*                                                                              *
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+ +                                                                            + +
+ +                      ASPEN PLUS CALCULATION REPORT                         + +
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PLATFORM: WINDOWS
VERSION: 36.0 Build 250 Patchlevel 1
INSTALLATION:

APRIL 15, 2019
MONDAY
3:55:15 P.M.

TABLE OF CONTENTS

RUN CONTROL SECTION

RUN CONTROL INFORMATION

THIS COPY OF ASPEN PLUS LICENSED TO UNIVERSITY OF PENNSYLVAN

TYPE OF RUN: NEW

INPUT FILE NAME: _4409wnp.inm

OUTPUT PROBLEM DATA FILE NAME: _5510ttn
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:
NUMBER OF FILE RECORDS (PSIZE) = 0
NUMBER OF IN-CORE RECORDS = 256
PSIZE NEEDED FOR SIMULATION = 1

CALLING PROGRAM NAME: apmain
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V10.0\Engine\\xeq

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
SYNGASC	----	FTFEEDHX	FTCWIN	----	FTPRODHX
FTPRODH	FTREACT	FTFEEDHX	FTPRODW	FTFEEDHX	FTPRODHX
SYNGASH	FTFEEDHX	FTHEAT	FTFEED	FTHEAT	FTREACT
FTPRODC	FTPRODHX	----	FTCWOUT	FTPRODHX	----

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
FTREACT	FTFEED	FTPRODH
FTFEEDHX	FTPRODH SYNGASC	FTPRODW SYNGASH
FTHEAT	SYNGASH	FTFEED
FTPRODHX	FTPRODW FTCWIN	FTPRODC FTCWOUT

CONVERGENCE STATUS SUMMARY

DESIGN-SPEC SUMMARY

```
  ===================


  DESIGN                                                         CONV
  SPEC      ERROR        TOLERANCE    ERR/TOL      VARIABLE   STAT  BLOCK
  ------    -----        ---------    -------      --------   ----  -----
  FTCWTEMP  0.57067E-05  0.10000E-02  0.57067E-02  0.58273E+06 #    $OLVER02

  TEAR STREAM SUMMARY
  ===================


  STREAM    VARIABLE         MAXIMUM      MAX. ERR.    ABSOLUTE          CONV
  ID        ID               ERR/TOL      RELATIVE     ERROR        STAT  BLOCK
  ------    --------         --------     -------      ---------    ----  -----
  SYNGASH  CO MOLEFLOW        0.0000       0.0000       0.0000      #
  $OLVER01


  #  = CONVERGED
  *  = NOT CONVERGED
  LB = AT LOWER BOUNDS
  UB = AT UPPER BOUNDS

DESIGN-SPEC:  FTCWTEMP
----------------------

  SAMPLED VARIABLES:
    CWOUT    : TEMPERATURE IN STREAM FTCWOUT SUBSTREAM MIXED

  SPECIFICATION:
    MAKE CWOUT APPROACH 48.8900
    WITHIN          0.00100000
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                             FLOWSHEET SECTION

DESIGN-SPEC:  FTCWTEMP (CONTINUED)

  MANIPULATED VARIABLES:
    VARY     : TOTAL MASSFLOW IN STREAM FTCWIN SUBSTREAM MIXED
    LOWER LIMIT =          11.0231                    LB/HR
    UPPER LIMIT =           0.220462+09               LB/HR
    FINAL VALUE =     582,732.                        LB/HR

  VALUES OF ACCESSED FORTRAN VARIABLES:
    VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                     OF LOOP
    --------      --------------      -----------     -----
    CWOUT           142.939            48.8900       C

CONVERGENCE BLOCK:  $OLVER01
----------------------------
    Tear Stream  :  SYNGASH
    Tolerance used:  0.100D-03
    Trace molefrac:  0.100D-05

    MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
    QMAX =   0.0     QMIN =  -5.0
    METHOD: WEGSTEIN      STATUS: CONVERGED
    TOTAL NUMBER OF ITERATIONS:     3
    NUMBER OF ITERATIONS ON LAST OUTER LOOP:     0

                        *** FINAL VALUES ***

VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
```

```
      VALUE       PREV VALUE       ERR/TOL
7617  ----  ---------------  -------- -------- -------- -------- -------- -----------
      ------------   ------------   ------------
7618     1  TOTAL MOLEFLOW   SYNGASH  MIXED                                LBMOL/HR
         6715.8129      6715.8129         0.0
7619     2  MOLE-FLOW        SYNGASH  MIXED    CO                          LBMOL/HR
         831.9090       831.9090          0.0
7620     3  MOLE-FLOW        SYNGASH  MIXED    CO2                         LBMOL/HR
         395.9019       395.9019          0.0
7621     4  MOLE-FLOW        SYNGASH  MIXED    H2                          LBMOL/HR
         5337.1641      5337.1641         0.0
7622     5  MOLE-FLOW        SYNGASH  MIXED    H2O                         LBMOL/HR
         150.8379       150.8379          0.0
7623     6  MOLE-FLOW        SYNGASH  MIXED    CH4                         LBMOL/HR
         0.0            0.0               0.0
7624     7  MOLE-FLOW        SYNGASH  MIXED    C2H6                        LBMOL/HR
         0.0            0.0               0.0
7625     8  MOLE-FLOW        SYNGASH  MIXED    C3H8                        LBMOL/HR
         0.0            0.0               0.0
7626     9  MOLE-FLOW        SYNGASH  MIXED    C4H10                       LBMOL/HR
         0.0            0.0               0.0
7627    10  MOLE-FLOW        SYNGASH  MIXED    C5H12                       LBMOL/HR
         0.0            0.0               0.0
7628    11  MOLE-FLOW        SYNGASH  MIXED    C6H14                       LBMOL/HR
         0.0            0.0               0.0
7629    12  MOLE-FLOW        SYNGASH  MIXED    C7H16                       LBMOL/HR
         0.0            0.0               0.0
7630    13  MOLE-FLOW        SYNGASH  MIXED    C8H18                       LBMOL/HR
         0.0            0.0               0.0
7631    14  MOLE-FLOW        SYNGASH  MIXED    C9H20                       LBMOL/HR
         0.0            0.0               0.0
7632    15  MOLE-FLOW        SYNGASH  MIXED    C10H22                      LBMOL/HR
         0.0            0.0               0.0
7633    16  MOLE-FLOW        SYNGASH  MIXED    C11H24                      LBMOL/HR
         0.0            0.0               0.0
7634    17  MOLE-FLOW        SYNGASH  MIXED    C12H26                      LBMOL/HR
         0.0            0.0               0.0
7635    18  MOLE-FLOW        SYNGASH  MIXED    C13H28                      LBMOL/HR
         0.0            0.0               0.0
7636    19  MOLE-FLOW        SYNGASH  MIXED    C14H30                      LBMOL/HR
         0.0            0.0               0.0
7637    20  MOLE-FLOW        SYNGASH  MIXED    C15H32                      LBMOL/HR
         0.0            0.0               0.0
7638 FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 4
7639
7640                                FLOWSHEET SECTION
7641
7642  CONVERGENCE BLOCK:  $OLVER01 (CONTINUED)
7643    21  MOLE-FLOW        SYNGASH  MIXED    C16H34                      LBMOL/HR
         0.0            0.0               0.0
7644    22  MOLE-FLOW        SYNGASH  MIXED    C17H36                      LBMOL/HR
         0.0            0.0               0.0
7645    23  MOLE-FLOW        SYNGASH  MIXED    C18H38                      LBMOL/HR
         0.0            0.0               0.0
7646    24  MOLE-FLOW        SYNGASH  MIXED    C19H40                      LBMOL/HR
         0.0            0.0               0.0
7647    25  MOLE-FLOW        SYNGASH  MIXED    C20H42                      LBMOL/HR
         0.0            0.0               0.0
7648    26  MOLE-FLOW        SYNGASH  MIXED    C21H44                      LBMOL/HR
         0.0            0.0               0.0
7649    27  MOLE-FLOW        SYNGASH  MIXED    C22H46                      LBMOL/HR
         0.0            0.0               0.0
7650    28  MOLE-FLOW        SYNGASH  MIXED    C23H48                      LBMOL/HR
         0.0            0.0               0.0
7651    29  MOLE-FLOW        SYNGASH  MIXED    C24H50                      LBMOL/HR
         0.0            0.0               0.0
```

```
7652     30  MOLE-FLOW        SYNGASH  MIXED    C25H52                      LBMOL/HR
         0.0            0.0            0.0
7653     31  MOLE-FLOW        SYNGASH  MIXED    C26H54                      LBMOL/HR
         0.0            0.0            0.0
7654     32  MOLE-FLOW        SYNGASH  MIXED    C27H56                      LBMOL/HR
         0.0            0.0            0.0
7655     33  MOLE-FLOW        SYNGASH  MIXED    C28H58                      LBMOL/HR
         0.0            0.0            0.0
7656     34  MOLE-FLOW        SYNGASH  MIXED    C29H60                      LBMOL/HR
         0.0            0.0            0.0
7657     35  MOLE-FLOW        SYNGASH  MIXED    C30H62                      LBMOL/HR
         0.0            0.0            0.0
7658     36  MOLE-FLOW        SYNGASH  MIXED    C50H102                     LBMOL/HR
         0.0            0.0            0.0
7659     37  PRESSURE         SYNGASH  MIXED                                PSIA
         357.9807       357.9807         0.0
7660     38  MASS ENTHALPY    SYNGASH  MIXED                                BTU/LB
         -1857.9920     -1857.9920         0.0
7661
7662                            *** ITERATION HISTORY ***
7663
7664        TEAR STREAMS AND TEAR VARIABLES:
7665
7666        ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
           ATTRIBUT ELEMENT
7667        ---------   ----------- ----  ---------      ---------------- -------- --------
           -------- -------
7668             1      0.1000E+07    37  SYNGASH        PRESSURE
           MIXED
7669             2       1401.        38  SYNGASH        MASS ENTHALPY
           MIXED
7670             3       0.000         2  SYNGASH        MOLE-FLOW        MIXED
           CO
7671
7672     CONVERGENCE BLOCK:  $OLVER02
7673     ----------------------------
7674        SPECS: FTCWTEMP
7675        MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
7676                    MAX-STEP=       100.    % OF RANGE
7677                    XTOL=       1.000000E-08
7678        THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
7679        METHOD: SECANT        STATUS: CONVERGED
7680        TOTAL NUMBER OF ITERATIONS:     6
7681        NUMBER OF ITERATIONS ON LAST OUTER LOOP:     0
7682
7683                            *** FINAL VALUES ***
7684
7685
7686   VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                          UNIT
       VALUE       PREV VALUE       ERR/TOL
7687   ----  ---------------- -------------------------                    -----------
       ------------   ------------   ------------
7688      1  TOTAL MASSFLOW   FTCWIN.MIXED.TOTAL.MASSFLOW                 LB/HR
          5.8273+05      5.8876+05      5.7067-03
7689
7690                            *** ITERATION HISTORY ***
7691   FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 5
7692
7693                                FLOWSHEET SECTION
7694
7695     CONVERGENCE BLOCK:  $OLVER02 (CONTINUED)
7696
7697        DESIGN-SPEC ID:
           FTCWTEMP

7698        ITERATED:  TOTAL MASSFLOW IN STREAM FTCWIN SUBSTREAM MIXED
```

ITERATION	VARIABLE	ERROR	ERR/TOL
1	220.5	94.05	0.9405E+05
2	0.2205E+07	-12.40	-0.1240E+05
3	0.1948E+07	-11.81	-0.1181E+05
4	0.5362E+06	1.453	1453.
5	0.5888E+06	-0.1712	-171.2
6	0.5827E+06	0.5707E-05	0.5707E-02

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:
$OLVER01 FTHEAT FTREACT FTFEEDHX
(RETURN $OLVER01)
$OLVER02 FTPRODHX
(RETURN $OLVER02)

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)				
CO	831.909	1.19795	-830.711	-0.664605E-16
CO2	395.902	395.902	0.00000	0.00000
H2	5337.16	3560.68	-1776.49	0.00000
H2O	32497.4	33328.1	830.711	0.00000
CH4	0.00000	15.2239	15.2239	0.00000
C2H6	0.00000	13.2274	13.2274	0.00000
C3H8	0.00000	11.4803	11.4803	0.00000
C4H10	0.00000	10.0037	10.0037	0.00000
C5H12	0.00000	8.70177	8.70177	0.00000
C6H14	0.00000	7.57037	7.57037	0.00000
C7H16	0.00000	6.59585	6.59585	0.00000
C8H18	0.00000	5.72977	5.72977	0.00000
C9H20	0.00000	4.99145	4.99145	0.00000
C10H22	0.00000	4.34256	4.34256	0.00000
C11H24	0.00000	3.77384	3.77384	0.00000
C12H26	0.00000	3.28604	3.28604	0.00000
C13H28	0.00000	2.85409	2.85409	0.00000
C14H30	0.00000	2.48384	2.48384	0.00000
C15H32	0.00000	2.16296	2.16296	0.00000
C16H34	0.00000	1.87180	1.87180	0.00000
C17H36	0.00000	1.61488	1.61488	0.00000
C18H38	0.00000	1.43273	1.43273	0.00000
C19H40	0.00000	1.22597	1.22597	0.00000
C20H42	0.00000	1.08148	1.08148	0.00000
C21H44	0.00000	0.950753	0.950753	0.00000

OVERALL FLOWSHEET BALANCE (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)				
C22H46	0.00000	0.794095	0.794095	0.00000
C23H48	0.00000	0.708931	0.708931	0.00000
C24H50	0.00000	0.616999	0.616999	0.00000
C25H52	0.00000	0.535749	0.535749	0.00000
C26H54	0.00000	0.467149	0.467149	0.00000

C27H56	0.00000	0.406711	0.406711	0.00000
C28H58	0.00000	0.353561	0.353561	0.00000
C29H60	0.00000	0.306946	0.306946	0.00000
C30H62	0.00000	0.267875	0.267875	0.00000
C50H102	0.00000	0.00000	0.00000	0.00000
TOTAL BALANCE				
MOLE(LBMOL/HR)	39062.3	37400.9	-1661.42	0.00000
MASS(LB/HR)	636934.	636934.		0.00000
ENTHALPY(BTU/HR)	-0.408435E+10	-0.414084E+10		0.136417E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	17423.6	LB/HR
PRODUCT STREAMS CO2E	23529.4	LB/HR
NET STREAMS CO2E PRODUCTION	6105.85	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	6105.85	LB/HR

PHYSICAL PROPERTIES SECTION

COMPONENTS

ID	TYPE	ALIAS	NAME
CO	C	CO	CARBON-MONOXIDE
CO2	C	CO2	CARBON-DIOXIDE
H2	C	H2	HYDROGEN
H2O	C	H2O	WATER
CH4	C	CH4	METHANE
C2H6	C	C2H6	ETHANE
C3H8	C	C3H8	PROPANE
C4H10	C	C4H10-1	N-BUTANE
C5H12	C	C5H12-1	N-PENTANE
C6H14	C	C6H14-1	N-HEXANE
C7H16	C	C7H16-1	N-HEPTANE
C8H18	C	C8H18-1	N-OCTANE
C9H20	C	C9H20-1	N-NONANE
C10H22	C	C10H22-1	N-DECANE
C11H24	C	C11H24	N-UNDECANE
C12H26	C	C12H26	N-DODECANE
C13H28	C	C13H28	N-TRIDECANE
C14H30	C	C14H30	N-TETRADECANE
C15H32	C	C15H32	N-PENTADECANE
C16H34	C	C16H34	N-HEXADECANE
C17H36	C	C17H36	N-HEPTADECANE
C18H38	C	C18H38	N-OCTADECANE
C19H40	C	C19H40	N-NONADECANE
C20H42	C	C20H42	N-EICOSANE
C21H44	C	C21H44	N-HENEICOSANE
C22H46	C	C22H46	N-DOCOSANE
C23H48	C	C23H48	N-TRICOSANE
C24H50	C	C24H50	N-TETRACOSANE
C25H52	C	C25H52	N-PENTACOSANE
C26H54	C	C26H54	N-HEXACOSANE
C27H56	C	C27H56	N-HEPTACOSANE
C28H58	C	C28H58	N-OCTACOSANE
C29H60	C	C29H60	N-NONACOSANE
C30H62	C	C30H62	N-TRIACONTANE
C50H102	C	C50H102	PENTACONTANE

U-O-S BLOCK SECTION

BLOCK: FTFEEDHX MODEL: HEATX

HOT SIDE:

```
     ---------
     INLET STREAM:             FTPRODH
     OUTLET STREAM:            FTPRODW
     PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS
     COLD SIDE:
     ----------
     INLET STREAM:             SYNGASC
     OUTLET STREAM:            SYNGASH
     PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT        RELATIVE DIFF.
      TOTAL BALANCE
         MOLE(LBMOL/HR)            11770.2         11770.2          0.00000
         MASS(LB/HR   )            108404.         108404.          0.00000
         ENTHALPY(BTU/HR  )     -0.274310E+09   -0.274310E+09     0.00000

                        ***  CO2 EQUIVALENT SUMMARY ***
      FEED STREAMS CO2E             40953.0      LB/HR
      PRODUCT STREAMS CO2E          40953.0      LB/HR
      NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
      UTILITIES CO2E PRODUCTION     0.00000      LB/HR
      TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***

     FLASH SPECS FOR HOT SIDE:
     TWO    PHASE      FLASH
     MAXIMUM NO. ITERATIONS                                  30
     CONVERGENCE TOLERANCE                                    0.000100000

     FLASH SPECS FOR COLD SIDE:
     TWO    PHASE      FLASH
     MAXIMUM NO. ITERATIONS                                  30
     CONVERGENCE TOLERANCE                                    0.000100000

     FLOW DIRECTION AND SPECIFICATION:
       COUNTERCURRENT   HEAT EXCHANGER
       SPECIFIED COLD APPROACH TEMP
       SPECIFIED VALUE                C                      27.7800
       TEMPERATURE TOLERANCE          C                       0.01000
       LMTD CORRECTION FACTOR                                 1.00000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/15/2019  PAGE 9

                                U-O-S BLOCK SECTION

 BLOCK:  FTFEEDHX MODEL: HEATX (CONTINUED)

     PRESSURE SPECIFICATION:
       HOT  SIDE PRESSURE DROP        PSI                     0.0000
       COLD SIDE PRESSURE DROP        PSI                     0.0000

     HEAT TRANSFER COEFFICIENT SPECIFICATION:
       HOT LIQUID    COLD LIQUID      BTU/HR-SQFT-R         149.6937
       HOT 2-PHASE   COLD LIQUID      BTU/HR-SQFT-R         149.6937
       HOT VAPOR     COLD LIQUID      BTU/HR-SQFT-R         149.6937
       HOT LIQUID    COLD 2-PHASE     BTU/HR-SQFT-R         149.6937
       HOT 2-PHASE   COLD 2-PHASE     BTU/HR-SQFT-R         149.6937
       HOT VAPOR     COLD 2-PHASE     BTU/HR-SQFT-R         149.6937
       HOT LIQUID    COLD VAPOR       BTU/HR-SQFT-R         149.6937
       HOT 2-PHASE   COLD VAPOR       BTU/HR-SQFT-R         149.6937
       HOT VAPOR     COLD VAPOR       BTU/HR-SQFT-R         149.6937

                             ***  OVERALL RESULTS  ***

     STREAMS:
```

```
                  ----------------------------------------
                  |                                      |
FTPRODH   ----->|                HOT                   |-----> FTPRODW
T=  3.0000D+02  |                                      |       T=  1.4394D+02
P=  3.6259D+02  |                                      |       P=  3.6259D+02
V=  1.0000D+00  |                                      |       V=  9.5576D-01
                |                                      |
SYNGASH   <-----|                COLD                  |<----- SYNGASC
T=  2.7222D+02  |                                      |       T=  8.4302D+01
P=  3.5798D+02  |                                      |       P=  3.5798D+02
V=  1.0000D+00  |                                      |       V=  1.0000D+00
                  ----------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY           BTU/HR            16407632.5159
  CALCULATED (REQUIRED) AREA     SQFT                  1564.8762
  ACTUAL EXCHANGER AREA          SQFT                  1564.8762
  PER CENT OVER-DESIGN                                    0.0000

HEAT TRANSFER COEFFICIENT:
  AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R          149.6937
  UA (DIRTY)                     BTU/HR-R            234252.0439

LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                  1.0000
  LMTD (CORRECTED)               C                       38.9126
  NUMBER OF SHELLS IN SERIES                            1

PRESSURE DROP:
  HOTSIDE, TOTAL                 PSI                      0.0000
  COLDSIDE, TOTAL                PSI                      0.0000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/15/2019  PAGE 10

                            U-O-S BLOCK SECTION

BLOCK:  FTFEEDHX MODEL: HEATX (CONTINUED)

                       ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                                  HOT
        -------------------------------------------------------------
        |                             |                             |
HOT IN  |            VAP              |           COND              | HOT OUT
------> |                             |                             |------>
 300.0  |                        280.7|                             |  143.9
        |                             |                             |
COLDOUT |            VAP              |           VAP               | COLDIN
<------ |                             |                             |<------
 272.2  |                        254.3|                             |   84.3
        |                             |                             |
        -------------------------------------------------------------
                                  COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
             BTU/HR          SQFT        C         BTU/HR-SQFT-R   BTU/HR-R
    1    1580879.029      216.4855      27.1015   149.6937       32406.5134
    2   14826753.487     1348.3907      40.8089   149.6937      201845.5305
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/15/2019  PAGE 11

                            U-O-S BLOCK SECTION

HEATX COLD-TQCU FTFEEDHX TQCURV INLET
```

```
  ------------------------------------
    PRESSURE PROFILE:      CONSTANT2
    PRESSURE DROP:         0.0         PSI
    PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

  ----------------------------------------------------
  !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
  !            !            !            !            !
  !            !            !            !            !
  !            !            !            !            !
  !  BTU/HR    !  PSIA      !  C         !            !
  !            !            !            !            !
  !============!============!============!============!
  !     0.0    !   357.9807 !   272.2200 !     1.0000 !
  !  7.8132+05 !   357.9807 !   263.3528 !     1.0000 !
  !  1.5626+06 !   357.9807 !   254.4790 !     1.0000 !
  !  1.5809+06 !   357.9807 !   254.2718 !     1.0000 !
  !  2.3439+06 !   357.9807 !   245.5985 !     1.0000 !
  !------------+------------+------------+------------!
  !  3.1253+06 !   357.9807 !   236.7112 !     1.0000 !
  !  3.9066+06 !   357.9807 !   227.8170 !     1.0000 !
  !  4.6879+06 !   357.9807 !   218.9157 !     1.0000 !
  !  5.4692+06 !   357.9807 !   210.0071 !     1.0000 !
  !  6.2505+06 !   357.9807 !   201.0909 !     1.0000 !
  !------------+------------+------------+------------!
  !  7.0318+06 !   357.9807 !   192.1670 !     1.0000 !
  !  7.8132+06 !   357.9807 !   183.2350 !     1.0000 !
  !  8.5945+06 !   357.9807 !   174.2944 !     1.0000 !
  !  9.3758+06 !   357.9807 !   165.3450 !     1.0000 !
  !  1.0157+07 !   357.9807 !   156.3862 !     1.0000 !
  !------------+------------+------------+------------!
  !  1.0938+07 !   357.9807 !   147.4174 !     1.0000 !
  !  1.1720+07 !   357.9807 !   138.4382 !     1.0000 !
  !  1.2501+07 !   357.9807 !   129.4479 !     1.0000 !
  !  1.3282+07 !   357.9807 !   120.4457 !     1.0000 !
  !  1.4064+07 !   357.9807 !   111.4310 !     1.0000 !
  !------------+------------+------------+------------!
  !  1.4845+07 !   357.9807 !   102.4027 !     1.0000 !
  !  1.5626+07 !   357.9807 !    93.3602 !     1.0000 !
  !  1.6408+07 !   357.9807 !    84.3024 !     1.0000 !
  ----------------------------------------------------
FE ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 12

                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR FTFEEDHX TQCURV INLET
 ------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

  ----------------------------------------------------
  !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
  !            !            !            !            !
  !            !            !            !            !
  !            !            !            !            !
  !  BTU/HR    !  PSIA      !  C         !            !
  !            !            !            !            !
  !============!============!============!============!
  !     0.0    !   362.5943 !   300.0000 !     1.0000 !
  !  7.8132+05 !   362.5943 !   290.4795 !     1.0000 !
  !  1.5626+06 !   362.5943 !   280.9303 !     1.0000 !
  !  1.5809+06 !   362.5943 !   280.7071 ! DEW>1.0000 !
  !  2.3439+06 !   362.5943 !   271.9193 !     0.9997 !
  !------------+------------+------------+------------!
  !  3.1253+06 !   362.5943 !   262.9000 !     0.9994 !
```

```
 !  3.9066+06 !   362.5943 !   253.8740 !     0.9990 !
 !  4.6879+06 !   362.5943 !   244.8523 !     0.9987 !
 !  5.4692+06 !   362.5943 !   235.8420 !     0.9982 !
 !  6.2505+06 !   362.5943 !   226.8473 !     0.9978 !
 !------------+------------+------------+------------!
 !  7.0318+06 !   362.5943 !   217.8703 !     0.9972 !
 !  7.8132+06 !   362.5943 !   208.9157 !     0.9967 !
 !  8.5945+06 !   362.5943 !   199.9947 !     0.9960 !
 !  9.3758+06 !   362.5943 !   191.1306 !     0.9953 !
 !  1.0157+07 !   362.5943 !   182.3649 !     0.9944 !
 !------------+------------+------------+------------!
 !  1.0938+07 !   362.5943 !   173.7807 !     0.9933 !
 !  1.1720+07 !   362.5943 !   165.5614 !     0.9917 !
 !  1.2501+07 !   362.5943 !   158.2106 !     0.9893 !
 !  1.3282+07 !   362.5943 !   152.9646 !     0.9848 !
 !  1.4064+07 !   362.5943 !   149.7177 !     0.9784 !
 !------------+------------+------------+------------!
 !  1.4845+07 !   362.5943 !   147.4356 !     0.9712 !
 !  1.5626+07 !   362.5943 !   145.6029 !     0.9635 !
 !  1.6408+07 !   362.5943 !   143.9394 !     0.9558 !
 ------------------------------------------------------

 BLOCK:  FTHEAT   MODEL: HEATER
 ------------------------------
   INLET STREAM:          SYNGASH
   OUTLET STREAM:         FTFEED
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 13

                              U-O-S BLOCK SECTION

 BLOCK:  FTHEAT   MODEL: HEATER (CONTINUED)
    TOTAL BALANCE
       MOLE(LBMOL/HR)            6715.81         6715.81         0.00000
       MASS(LB/HR   )            54202.1         54202.1         0.00000
       ENTHALPY(BTU/HR  )     -0.100707E+09   -0.982556E+08   -0.243435E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             17423.6      LB/HR
    PRODUCT STREAMS CO2E          17423.6      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED TEMPERATURE               C                      300.000
   SPECIFIED PRESSURE                  PSIA                   362.594
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE                                        0.000100000



                            ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                   300.00
   OUTLET PRESSURE       PSIA                                362.59
   HEAT DUTY             BTU/HR                           0.24516E+07
```

```
 BLOCK:  FTPRODHX MODEL: HEATX
 ------------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             FTPRODW
   OUTLET STREAM:            FTPRODC
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS
   COLD SIDE:
   ----------
   INLET STREAM:             FTCWIN
   OUTLET STREAM:            FTCWOUT
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            37400.9         37400.9         0.00000
       MASS(LB/HR   )            636934.         636934.         0.00000
       ENTHALPY(BTU/HR  )     -0.414084E+10   -0.414084E+10     0.00000
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 14

                             U-O-S BLOCK SECTION

 BLOCK:  FTPRODHX MODEL: HEATX (CONTINUED)

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             23529.4      LB/HR
    PRODUCT STREAMS CO2E          23529.4      LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE               C                       80.0000
     LMTD CORRECTION FACTOR                                   1.00000

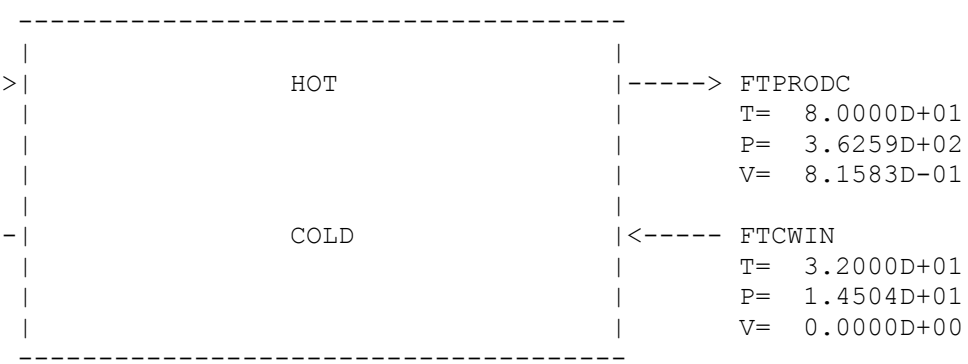
   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP       PSI                       0.0000
     COLD SIDE PRESSURE DROP       PSI                       0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID     BTU/HR-SQFT-R          149.6937
     HOT 2-PHASE   COLD LIQUID     BTU/HR-SQFT-R          149.6937
     HOT VAPOR     COLD LIQUID     BTU/HR-SQFT-R          149.6937
     HOT LIQUID    COLD 2-PHASE    BTU/HR-SQFT-R          149.6937
     HOT 2-PHASE   COLD 2-PHASE    BTU/HR-SQFT-R          149.6937
     HOT VAPOR     COLD 2-PHASE    BTU/HR-SQFT-R          149.6937
     HOT LIQUID    COLD VAPOR      BTU/HR-SQFT-R          149.6937
     HOT 2-PHASE   COLD VAPOR      BTU/HR-SQFT-R          149.6937
     HOT VAPOR     COLD VAPOR      BTU/HR-SQFT-R          149.6937
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 15
```

BLOCK: FTPRODHX MODEL: HEATX (CONTINUED)

*** OVERALL RESULTS ***

STREAMS:



DUTY AND AREA:

CALCULATED HEAT DUTY	BTU/HR	17698963.7113
CALCULATED (REQUIRED) AREA	SQFT	953.8125
ACTUAL EXCHANGER AREA	SQFT	953.8125
PER CENT OVER-DESIGN		0.0000

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY)	BTU/HR-SQFT-R	149.6937
UA (DIRTY)	BTU/HR-R	142779.6797

LOG-MEAN TEMPERATURE DIFFERENCE:

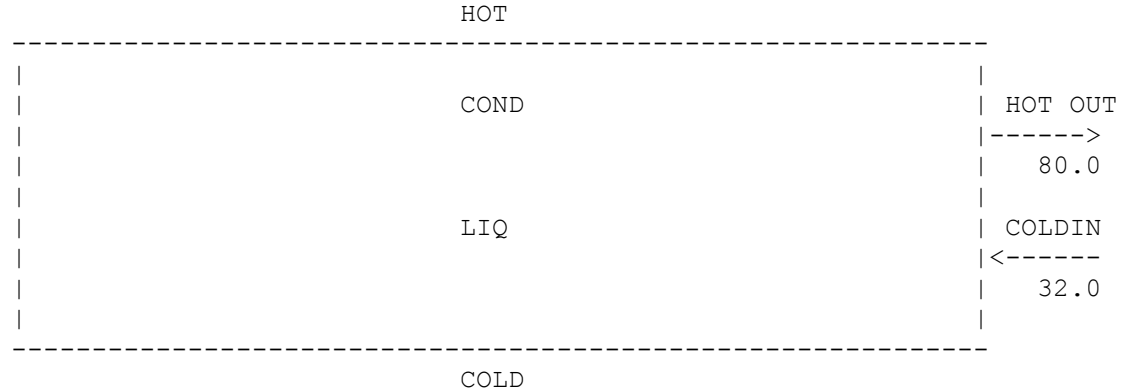
LMTD CORRECTION FACTOR		1.0000
LMTD (CORRECTED)	C	68.8666
NUMBER OF SHELLS IN SERIES		1

PRESSURE DROP:

HOTSIDE, TOTAL	PSI	0.0000
COLDSIDE, TOTAL	PSI	0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:



BLOCK: FTPRODHX MODEL: HEATX (CONTINUED)

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY BTU/HR	AREA SQFT	LMTD C	AVERAGE U BTU/HR-SQFT-R	UA BTU/HR-R

```
     1   17698963.711       953.8125      68.8666   149.6937      142779.6797
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 17

                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU FTPRODHX TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

 ------------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    14.5038 !    48.8900 !     0.0    !
 !  8.4281+05 !    14.5038 !    48.0928 !     0.0    !
 !  1.6856+06 !    14.5038 !    47.2948 !     0.0    !
 !  2.5284+06 !    14.5038 !    46.4961 !     0.0    !
 !  3.3712+06 !    14.5038 !    45.6967 !     0.0    !
 !------------+------------+------------+------------!
 !  4.2140+06 !    14.5038 !    44.8966 !     0.0    !
 !  5.0568+06 !    14.5038 !    44.0957 !     0.0    !
 !  5.8997+06 !    14.5038 !    43.2941 !     0.0    !
 !  6.7425+06 !    14.5038 !    42.4918 !     0.0    !
 !  7.5853+06 !    14.5038 !    41.6889 !     0.0    !
 !------------+------------+------------+------------!
 !  8.4281+06 !    14.5038 !    40.8852 !     0.0    !
 !  9.2709+06 !    14.5038 !    40.0808 !     0.0    !
 !  1.0114+07 !    14.5038 !    39.2757 !     0.0    !
 !  1.0957+07 !    14.5038 !    38.4700 !     0.0    !
 !  1.1799+07 !    14.5038 !    37.6635 !     0.0    !
 !------------+------------+------------+------------!
 !  1.2642+07 !    14.5038 !    36.8564 !     0.0    !
 !  1.3485+07 !    14.5038 !    36.0487 !     0.0    !
 !  1.4328+07 !    14.5038 !    35.2402 !     0.0    !
 !  1.5171+07 !    14.5038 !    34.4311 !     0.0    !
 !  1.6013+07 !    14.5038 !    33.6214 !     0.0    !
 !------------+------------+------------+------------!
 !  1.6856+07 !    14.5038 !    32.8110 !     0.0    !
 !  1.7699+07 !    14.5038 !    32.0000 !     0.0    !
 ------------------------------------------------------
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/15/2019  PAGE 18

                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR FTPRODHX TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         PSI
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

 ------------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !   362.5943 !   143.9394 !     0.9558 !
 !  8.4281+05 !   362.5943 !   142.1846 !     0.9474 !
```

```
 !  1.6856+06 !   362.5943 !   140.4001 !     0.9391 !
 !  2.5284+06 !   362.5943 !   138.5524 !     0.9309 !
 !  3.3712+06 !   362.5943 !   136.6238 !     0.9228 !
 !------------+------------+------------+------------!
 !  4.2140+06 !   362.5943 !   134.6031 !     0.9148 !
 !  5.0568+06 !   362.5943 !   132.4810 !     0.9070 !
 !  5.8997+06 !   362.5943 !   130.2490 !     0.8994 !
 !  6.7425+06 !   362.5943 !   127.8982 !     0.8919 !
 !  7.5853+06 !   362.5943 !   125.4188 !     0.8846 !
 !------------+------------+------------+------------!
 !  8.4281+06 !   362.5943 !   122.8000 !     0.8774 !
 !  9.2709+06 !   362.5943 !   120.0294 !     0.8705 !
 !  1.0114+07 !   362.5943 !   117.0935 !     0.8638 !
 !  1.0957+07 !   362.5943 !   113.9767 !     0.8573 !
 !  1.1799+07 !   362.5943 !   110.6616 !     0.8511 !
 !------------+------------+------------+------------!
 !  1.2642+07 !   362.5943 !   107.1286 !     0.8451 !
 !  1.3485+07 !   362.5943 !   103.3560 !     0.8394 !
 !  1.4328+07 !   362.5943 !    99.3194 !     0.8340 !
 !  1.5171+07 !   362.5943 !    94.9972 !     0.8289 !
 !  1.6013+07 !   362.5943 !    90.3562 !     0.8242 !
 !------------+------------+------------+------------!
 !  1.6856+07 !   362.5943 !    85.3666 !     0.8198 !
 !  1.7699+07 !   362.5943 !    80.0000 !     0.8158 !
 ---------------------------------------------------

 BLOCK:  FTREACT  MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          FTFEED
   OUTLET STREAM:         FTPRODH
   PROPERTY OPTION SET:   UNIQUAC   UNIQUAC / IDEAL GAS

                        ***  MASS AND ENERGY BALANCE  ***
                                   IN          OUT       GENERATION   RELATIVE DIFF.
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                               U-O-S BLOCK SECTION

 BLOCK:  FTREACT  MODEL: RSTOIC (CONTINUED)
   TOTAL BALANCE
   MOLE(LBMOL/HR)         6715.81       5054.39      -1661.42      0.135426E-15
   MASS(LB/HR   )         54202.1       54202.1                   -0.536950E-15
   ENTHALPY(BTU/HR  )   -0.982556E+08 -0.157195E+09                0.374946

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             17423.6      LB/HR
    PRODUCT STREAMS CO2E          23529.4      LB/HR
    NET STREAMS CO2E PRODUCTION   6105.85      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         6105.85      LB/HR

                             ***  INPUT DATA  ***
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/15/2019  PAGE 20

                               U-O-S BLOCK SECTION

 BLOCK:  FTREACT  MODEL: RSTOIC (CONTINUED)
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     CO        -1.00    H2        -3.00    H2O        1.00    CH4        1.00

    REACTION #   2:
     SUBSTREAM MIXED   :
     CO        -2.00    H2        -5.00    H2O        2.00    C2H6       1.00
```

```
8359
8360       REACTION #   3:
8361        SUBSTREAM MIXED   :
8362        CO        -3.00    H2        -7.00    H2O        3.00    C3H8       1.00
8363
8364       REACTION #   4:
8365        SUBSTREAM MIXED   :
8366        CO        -4.00    H2        -9.00    H2O        4.00    C4H10      1.00
8367
8368       REACTION #   5:
8369        SUBSTREAM MIXED   :
8370        CO        -5.00    H2        -11.0    H2O        5.00    C5H12      1.00
8371
8372       REACTION #   6:
8373        SUBSTREAM MIXED   :
8374        CO        -6.00    H2        -13.0    H2O        6.00    C6H14      1.00
8375
8376       REACTION #   7:
8377        SUBSTREAM MIXED   :
8378        CO        -7.00    H2        -15.0    H2O        7.00    C7H16      1.00
8379
8380       REACTION #   8:
8381        SUBSTREAM MIXED   :
8382        CO        -8.00    H2        -17.0    H2O        8.00    C8H18      1.00
8383
8384       REACTION #   9:
8385        SUBSTREAM MIXED   :
8386        CO        -9.00    H2        -19.0    H2O        9.00    C9H20      1.00
8387
8388       REACTION #  10:
8389        SUBSTREAM MIXED   :
8390        CO        -10.0    H2        -21.0    H2O        10.0    C10H22     1.00
8391
8392       REACTION #  11:
8393        SUBSTREAM MIXED   :
8394        CO        -11.0    H2        -23.0    H2O        11.0    C11H24     1.00
8395
8396       REACTION #  12:
8397        SUBSTREAM MIXED   :
8398        CO        -12.0    H2        -25.0    H2O        12.0    C12H26     1.00
8399
8400       REACTION #  13:
8401        SUBSTREAM MIXED   :
8402        CO        -13.0    H2        -27.0    H2O        13.0    C13H28     1.00
8403
8404       REACTION #  14:
8405        SUBSTREAM MIXED   :
8406        CO        -14.0    H2        -29.0    H2O        14.0    C14H30     1.00
8407
8408       REACTION #  15:
8409        SUBSTREAM MIXED   :
8410        CO        -15.0    H2        -31.0    H2O        15.0    C15H32     1.00
8411
8412       REACTION #  16:
8413        SUBSTREAM MIXED   :
8414        CO        -16.0    H2        -33.0    H2O        16.0    C16H34     1.00
8415
8416       REACTION #  17:
8417        SUBSTREAM MIXED   :
8418        CO        -17.0    H2        -35.0    H2O        17.0    C17H36     1.00
8419
8420       REACTION #  18:
8421        SUBSTREAM MIXED   :
8422        CO        -18.0    H2        -37.0    H2O        18.0    C18H38     1.00
8423
8424       REACTION #  19:
```

```
 SUBSTREAM MIXED   :
 CO        -19.0    H2        -39.0    H2O        19.0    C19H40     1.00

REACTION #  20:
 SUBSTREAM MIXED   :
 CO        -20.0    H2        -41.0    H2O        20.0    C20H42     1.00

REACTION #  21:
 SUBSTREAM MIXED   :
 CO        -21.0    H2        -43.0    H2O        21.0    C21H44     1.00

REACTION #  22:
 SUBSTREAM MIXED   :
 CO        -22.0    H2        -45.0    H2O        22.0    C22H46     1.00

REACTION #  23:
 SUBSTREAM MIXED   :
 CO        -23.0    H2        -47.0    H2O        23.0    C23H48     1.00

REACTION #  24:
 SUBSTREAM MIXED   :
 CO        -24.0    H2        -49.0    H2O        24.0    C24H50     1.00

REACTION #  25:
 SUBSTREAM MIXED   :
 CO        -25.0    H2        -51.0    H2O        25.0    C25H52     1.00

REACTION #  26:
 SUBSTREAM MIXED   :
 CO        -26.0    H2        -53.0    H2O        26.0    C26H54     1.00

REACTION #  27:
 SUBSTREAM MIXED   :
 CO        -27.0    H2        -55.0    H2O        27.0    C27H56     1.00

REACTION #  28:
 SUBSTREAM MIXED   :
 CO        -28.0    H2        -57.0    H2O        28.0    C28H58     1.00

REACTION #  29:
 SUBSTREAM MIXED   :
 CO        -29.0    H2        -59.0    H2O        29.0    C29H60     1.00

REACTION #  30:
 SUBSTREAM MIXED   :
 CO        -30.0    H2        -61.0    H2O        30.0    C30H62     1.00


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                              U-O-S BLOCK SECTION

 BLOCK:  FTREACT  MODEL: RSTOIC (CONTINUED)
   REACTION CONVERSION SPECS: NUMBER=   30
     REACTION #   1:
     SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1830E-01
     REACTION #   2:
     SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.3180E-01
     REACTION #   3:
     SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.4140E-01
     REACTION #   4:
     SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.4810E-01
     REACTION #   5:
     SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.5230E-01
     REACTION #   6:
     SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.5460E-01
```

```
      REACTION #   7:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.5550E-01
      REACTION #   8:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.5510E-01
      REACTION #   9:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.5400E-01
      REACTION #  10:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.5220E-01
      REACTION #  11:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.4990E-01
      REACTION #  12:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.4740E-01
      REACTION #  13:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.4460E-01
      REACTION #  14:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.4180E-01
      REACTION #  15:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.3900E-01
      REACTION #  16:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.3600E-01
      REACTION #  17:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.3300E-01
      REACTION #  18:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.3100E-01
      REACTION #  19:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.2800E-01
      REACTION #  20:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.2600E-01
      REACTION #  21:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.2400E-01
      REACTION #  22:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.2100E-01
      REACTION #  23:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1960E-01
      REACTION #  24:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1780E-01
      REACTION #  25:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1610E-01
      REACTION #  26:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1460E-01
      REACTION #  27:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1320E-01
      REACTION #  28:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1190E-01
      REACTION #  29:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.1070E-01
      REACTION #  30:
      SUBSTREAM:MIXED    KEY COMP:CO       CONV FRAC: 0.9660E-02


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                              U-O-S BLOCK SECTION

 BLOCK:  FTREACT  MODEL: RSTOIC (CONTINUED)
   THREE  PHASE  TP  FLASH
   SPECIFIED TEMPERATURE C                                  300.000
   SPECIFIED PRESSURE    PSIA                               362.594
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES           NO

                           ***  RESULTS  ***
```

OUTLET TEMPERATURE	C		300.00
OUTLET PRESSURE	PSIA		362.59
HEAT DUTY	BTU/HR		-0.58940E+08
VAPOR FRACTION			1.0000
1ST LIQUID/TOTAL LIQUID			1.0000

U-O-S BLOCK SECTION

BLOCK: FTREACT MODEL: RSTOIC (CONTINUED)

REACTION EXTENTS:

REACTION NUMBER	REACTION EXTENT LBMOL/HR
1	15.224
2	13.227
3	11.480
4	10.004
5	8.7018
6	7.5704
7	6.5958
8	5.7298
9	4.9915
10	4.3426
11	3.7738
12	3.2860
13	2.8541
14	2.4838
15	2.1630
16	1.8718
17	1.6149
18	1.4327
19	1.2260
20	1.0815
21	0.95075
22	0.79409
23	0.70893
24	0.61700
25	0.53575
26	0.46715
27	0.40671
28	0.35356
29	0.30695
30	0.26787

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
CO	0.237E-03	0.141E-04	0.141E-04	0.237E-03	29.0	29.0
CO2	0.783E-01	0.722E-02	0.722E-02	0.783E-01	18.7	18.7
H2	0.704	0.192E-01	0.192E-01	0.704	63.2	63.2
H2O	0.194	0.187	0.187	0.194	1.79	1.79
CH4	0.301E-02	0.259E-03	0.259E-03	0.301E-02	20.0	20.0
C2H6	0.262E-02	0.389E-03	0.389E-03	0.262E-02	11.6	11.6
C3H8	0.227E-02	0.569E-03	0.569E-03	0.227E-02	6.88	6.88
C4H10	0.198E-02	0.801E-03	0.801E-03	0.198E-02	4.26	4.26
C5H12	0.172E-02	0.955E-03	0.955E-03	0.172E-02	3.11	3.11
C6H14	0.150E-02	0.121E-02	0.121E-02	0.150E-02	2.13	2.13
C7H16	0.130E-02	0.165E-02	0.165E-02	0.130E-02	1.37	1.37
C8H18	0.113E-02	0.207E-02	0.207E-02	0.113E-02	0.944	0.944
C9H20	0.988E-03	0.265E-02	0.265E-02	0.988E-03	0.641	0.641
C10H22	0.859E-03	0.329E-02	0.329E-02	0.859E-03	0.450	0.450
C11H24	0.747E-03	0.414E-02	0.414E-02	0.747E-03	0.310	0.310
C12H26	0.650E-03	0.520E-02	0.520E-02	0.650E-03	0.215	0.215

C13H28	0.565E-03	0.588E-02	0.588E-02	0.565E-03	0.166	0.166
C14H30	0.491E-03	0.745E-02	0.745E-02	0.491E-03	0.114	0.114

U-O-S BLOCK SECTION

BLOCK: FTREACT MODEL: RSTOIC (CONTINUED)

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
C15H32	0.428E-03	0.102E-01	0.102E-01	0.428E-03	0.722E-01	0.722E-01
C16H34	0.370E-03	0.102E-01	0.102E-01	0.370E-03	0.628E-01	0.628E-01
C17H36	0.320E-03	0.146E-01	0.146E-01	0.320E-03	0.378E-01	0.378E-01
C18H38	0.283E-03	0.174E-01	0.174E-01	0.283E-03	0.281E-01	0.281E-01
C19H40	0.243E-03	0.203E-01	0.203E-01	0.243E-03	0.206E-01	0.206E-01
C20H42	0.214E-03	0.248E-01	0.248E-01	0.214E-03	0.149E-01	0.149E-01
C21H44	0.188E-03	0.292E-01	0.292E-01	0.188E-03	0.111E-01	0.111E-01
C22H46	0.157E-03	0.324E-01	0.324E-01	0.157E-03	0.836E-02	0.836E-02
C23H48	0.140E-03	0.402E-01	0.402E-01	0.140E-03	0.602E-02	0.602E-02
C24H50	0.122E-03	0.475E-01	0.475E-01	0.122E-03	0.443E-02	0.443E-02
C25H52	0.106E-03	0.547E-01	0.547E-01	0.106E-03	0.334E-02	0.334E-02
C26H54	0.924E-04	0.655E-01	0.655E-01	0.924E-04	0.243E-02	0.243E-02
C27H56	0.805E-04	0.800E-01	0.800E-01	0.805E-04	0.173E-02	0.173E-02
C28H58	0.700E-04	0.887E-01	0.887E-01	0.700E-04	0.136E-02	0.136E-02
C29H60	0.607E-04	0.990E-01	0.990E-01	0.607E-04	0.106E-02	0.106E-02
C30H62	0.530E-04	0.115	0.115	0.530E-04	0.791E-03	0.791E-03

STREAM SECTION

FTCWIN FTCWOUT FTFEED FTPRODC FTPRODH

STREAM ID	FTCWIN	FTCWOUT	FTFEED	FTPRODC	FTPRODH
FROM :	----	FTPRODHX	FTHEAT	FTPRODHX	FTREACT
TO :	FTPRODHX	----	FTREACT	----	FTFEEDHX
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	VAPOR	MIXED	VAPOR
COMPONENTS: LBMOL/HR					
CO	0.0	0.0	831.9090	1.1979	1.1979
CO2	0.0	0.0	395.9019	395.9019	395.9019
H2	0.0	0.0	5337.1641	3560.6786	3560.6786
H2O	3.2347+04	3.2347+04	150.8379	981.5490	981.5490
CH4	0.0	0.0	0.0	15.2239	15.2239
C2H6	0.0	0.0	0.0	13.2274	13.2274
C3H8	0.0	0.0	0.0	11.4803	11.4803
C4H10	0.0	0.0	0.0	10.0037	10.0037
C5H12	0.0	0.0	0.0	8.7018	8.7018
C6H14	0.0	0.0	0.0	7.5704	7.5704
C7H16	0.0	0.0	0.0	6.5958	6.5958
C8H18	0.0	0.0	0.0	5.7298	5.7298
C9H20	0.0	0.0	0.0	4.9915	4.9915
C10H22	0.0	0.0	0.0	4.3426	4.3426
C11H24	0.0	0.0	0.0	3.7738	3.7738
C12H26	0.0	0.0	0.0	3.2860	3.2860
C13H28	0.0	0.0	0.0	2.8541	2.8541
C14H30	0.0	0.0	0.0	2.4838	2.4838
C15H32	0.0	0.0	0.0	2.1630	2.1630
C16H34	0.0	0.0	0.0	1.8718	1.8718
C17H36	0.0	0.0	0.0	1.6149	1.6149
C18H38	0.0	0.0	0.0	1.4327	1.4327
C19H40	0.0	0.0	0.0	1.2260	1.2260
C20H42	0.0	0.0	0.0	1.0815	1.0815
C21H44	0.0	0.0	0.0	0.9508	0.9508

C22H46	0.0	0.0	0.0	0.7941	0.7941
C23H48	0.0	0.0	0.0	0.7089	0.7089
C24H50	0.0	0.0	0.0	0.6170	0.6170
C25H52	0.0	0.0	0.0	0.5357	0.5357
C26H54	0.0	0.0	0.0	0.4671	0.4671
C27H56	0.0	0.0	0.0	0.4067	0.4067
C28H58	0.0	0.0	0.0	0.3536	0.3536
C29H60	0.0	0.0	0.0	0.3069	0.3069
C30H62	0.0	0.0	0.0	0.2679	0.2679
C50H102	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	3.2347+04	3.2347+04	6715.8129	5054.3909	5054.3909
LB/HR	5.8273+05	5.8273+05	5.4202+04	5.4202+04	5.4202+04
CUFT/HR	9455.6987	9617.1692	2.0506+05	7.7975+04	1.5433+05
STATE VARIABLES:					
TEMP C	32.0000	48.8900	300.0000	80.0000	300.0000
PRES PSIA	14.5038	14.5038	362.5943	362.5943	362.5943
VFRAC	0.0	0.0	1.0000	0.8158	1.0000
LFRAC	1.0000	1.0000	0.0	0.1842	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0

STREAM SECTION

FTCWIN FTCWOUT FTFEED FTPRODC FTPRODH (CONTINUED)

STREAM ID	FTCWIN	FTCWOUT	FTFEED	FTPRODC	FTPRODH
ENTHALPY:					
BTU/LBMOL	-1.2265+05	-1.2210+05	-1.4630+04	-3.7849+04	-3.1101+04
BTU/LB	-6807.9924	-6777.6200	-1812.7619	-3529.4147	-2900.1665
BTU/HR	-3.9672+09	-3.9495+09	-9.8256+07	-1.9130+08	-1.5720+08
ENTROPY:					
BTU/LBMOL-R	-38.5542	-37.5886	2.1511	-13.4125	-4.6659
BTU/LB-R	-2.1401	-2.0865	0.2665	-1.2507	-0.4351
DENSITY:					
LBMOL/CUFT	3.4208	3.3634	3.2751-02	6.4821-02	3.2751-02
LB/CUFT	61.6276	60.5929	0.2643	0.6951	0.3512
AVG MW	18.0153	18.0153	8.0708	10.7238	10.7238

STREAM SECTION

FTPRODW SYNGASC SYNGASH

STREAM ID	FTPRODW	SYNGASC	SYNGASH
FROM :	FTFEEDHX	----	FTFEEDHX
TO :	FTPRODHX	FTFEEDHX	FTHEAT
SUBSTREAM: MIXED			
PHASE:	MIXED	VAPOR	VAPOR
COMPONENTS: LBMOL/HR			
CO	1.1979	831.9090	831.9090
CO2	395.9019	395.9019	395.9019
H2	3560.6786	5337.1641	5337.1641
H2O	981.5490	150.8379	150.8379
CH4	15.2239	0.0	0.0
C2H6	13.2274	0.0	0.0
C3H8	11.4803	0.0	0.0
C4H10	10.0037	0.0	0.0
C5H12	8.7018	0.0	0.0
C6H14	7.5704	0.0	0.0
C7H16	6.5958	0.0	0.0
C8H18	5.7298	0.0	0.0
C9H20	4.9915	0.0	0.0

C10H22	4.3426	0.0	0.0
C11H24	3.7738	0.0	0.0
C12H26	3.2860	0.0	0.0
C13H28	2.8541	0.0	0.0
C14H30	2.4838	0.0	0.0
C15H32	2.1630	0.0	0.0
C16H34	1.8718	0.0	0.0
C17H36	1.6149	0.0	0.0
C18H38	1.4327	0.0	0.0
C19H40	1.2260	0.0	0.0
C20H42	1.0815	0.0	0.0
C21H44	0.9508	0.0	0.0
C22H46	0.7941	0.0	0.0
C23H48	0.7089	0.0	0.0
C24H50	0.6170	0.0	0.0
C25H52	0.5357	0.0	0.0
C26H54	0.4671	0.0	0.0
C27H56	0.4067	0.0	0.0
C28H58	0.3536	0.0	0.0
C29H60	0.3069	0.0	0.0
C30H62	0.2679	0.0	0.0
C50H102	0.0	0.0	0.0
TOTAL FLOW:			
LBMOL/HR	5054.3909	6715.8129	6715.8129
LB/HR	5.4202+04	5.4202+04	5.4202+04
CUFT/HR	1.0751+05	1.2953+05	1.9763+05
STATE VARIABLES:			
TEMP C	143.9394	84.3024	272.2200
PRES PSIA	362.5943	357.9807	357.9807
VFRAC	0.9558	1.0000	1.0000
LFRAC	4.4242-02	0.0	0.0
SFRAC	0.0	0.0	0.0

STREAM SECTION

FTPRODW SYNGASC SYNGASH (CONTINUED)

STREAM ID	FTPRODW	SYNGASC	SYNGASH
ENTHALPY:			
BTU/LBMOL	-3.4347+04	-1.7439+04	-1.4996+04
BTU/LB	-3202.8784	-2160.7039	-1857.9920
BTU/HR	-1.7360+08	-1.1711+08	-1.0071+08
ENTROPY:			
BTU/LBMOL-R	-8.4454	-1.2352	1.8138
BTU/LB-R	-0.7875	-0.1530	0.2247
DENSITY:			
LBMOL/CUFT	4.7011-02	5.1846-02	3.3981-02
LB/CUFT	0.5041	0.4184	0.2743
AVG MW	10.7238	8.0708	8.0708

PROBLEM STATUS SECTION

BLOCK STATUS

```
********************************************************************************
*                                                                              *
* Calculations were completed normally                                         *
*                                                                              *
* All Unit Operation blocks were completed normally                            *
*                                                                              *
* All streams were flashed normally                                            *
*                                                                              *
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 * All Convergence blocks were completed normally                          *
 *                                                                         *
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 ASPEN TECHNOLOGY, INC.                U.S.A. 888/996-7100
 781/221-6400                          EUROPE (44) 1189-226555

 PLATFORM: WINDOWS                                      APRIL 14, 2019
 VERSION: 36.0   Build 250 Patchlevel 1                 SUNDAY
 INSTALLATION:                                          12:22:29 P.M.
```


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RUN CONTROL SECTION

RUN CONTROL INFORMATION

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TYPE OF RUN: EDIT

INPUT FILE NAME: _0647ufl.inm

INPUT PROBLEM DATA FILE NAME : _0647ufl
OUTPUT PROBLEM DATA FILE NAME: _5007yql
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:
NUMBER OF FILE RECORDS (PSIZE) = 0
NUMBER OF IN-CORE RECORDS = 256
PSIZE NEEDED FOR SIMULATION = 1

CALLING PROGRAM NAME: apmain
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V10.0\Engine\\xeq

FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
FTPROD	----	FLASH1	DIESELHO	----	LIQ2HX1
MIDALK2	----	MIXER	GASES	DIST1	----
FLASHFE	DIST1	FUELHEAT	LIQ1COLD	DECANT1	MIXER
LIQ2	DECANT1	LIQ2HX1	FLASHGAS	FLASH1	COOLER1
FLASLIQ2	FLASH1	LIQFLAH	DIESELCO	LIQ2HX1	----
LIQ2WARM	LIQ2HX1	LUBEHX	COL1FEED	MIXER	DIST1
FLASHG2	FLASH3	----	FLASHLQ3	FLASH3	MIXER
HYDROCAR	DECANT2	LUBEHEAT	WATEROUT	DECANT2	----
MIDALK	FLASHLUB	----	LUBE	FLASHLUB	LUBEHX
GASOLINE	FLASH4	----	DIESEL	FLASH4	----
COLDFLAS	COOLER1	FLASH3	FUELFLAS	FUELHEAT	FLASH4
FEEDLUB	LUBEHEAT	FLASHLUB	LUBEOUT	LUBEHX	----
LIQ2WAMR	LUBEHX	DECANTH	LIQ2HOT	DECANTH	DECANT2
FLASHWRM	LIQFLAH	DECANT1			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
DIST1	COL1FEED	GASES FLASHFE
DECANT1	FLASHWRM	LIQ1COLD LIQ2
FLASH1	FTPROD	FLASHGAS FLASLIQ2
LIQ2HX1	DIESELHO LIQ2	DIESELCO LIQ2WARM
MIXER	FLASHLQ3 LIQ1COLD MIDALK2	COL1FEED
FLASH3	COLDFLAS	FLASHG2 FLASHLQ3
DECANT2	LIQ2HOT	HYDROCAR WATEROUT
FLASHLUB	FEEDLUB	MIDALK LUBE
FLASH4	FUELFLAS	GASOLINE DIESEL
COOLER1	FLASHGAS	COLDFLAS
FUELHEAT	FLASHFE	FUELFLAS
LUBEHEAT	HYDROCAR	FEEDLUB
LUBEHX	LUBE LIQ2WARM	LUBEOUT LIQ2WAMR
DECANTH	LIQ2WAMR	LIQ2HOT
LIQFLAH	FLASLIQ2	FLASHWRM

CONVERGENCE STATUS SUMMARY

DESIGN-SPEC SUMMARY

DESIGN SPEC	ERROR	TOLERANCE	ERR/TOL	VARIABLE	STAT	CONV BLOCK
FLAS1H2O	-0.36335E-04	0.10000E-02	-0.36335E-01	50.457	#	$OLVER02
FLASH2	0.31863E-03	0.10000E-02	0.31863	-59.602	#	$OLVER03

FLOWSHEET SECTION

CONVERGENCE STATUS SUMMARY (CONTINUED)

TEAR STREAM SUMMARY

```
      STREAM    VARIABLE         MAXIMUM      MAX. ERR.    ABSOLUTE          CONV
      ID        ID               ERR/TOL      RELATIVE     ERROR       STAT  BLOCK
      ------    --------         --------     -------      ---------   ----  -----
      LIQ2WAMR MASS ENTHALPY     0.51346E-03 -0.51346E-07  0.72519E-08  #
      $OLVER01


      #  = CONVERGED
      *  = NOT CONVERGED
      LB = AT LOWER BOUNDS
      UB = AT UPPER BOUNDS

    DESIGN-SPEC:  FLAS1H2O
    ----------------------

      SAMPLED VARIABLES:
        F1WATER  : WATER MOLEFLOW IN STREAM FLASLIQ2 SUBSTREAM MIXED
        FEEDH2O  : WATER MOLEFLOW IN STREAM FTPROD SUBSTREAM MIXED
        H2ORECOV : LOCAL-PARAM

      FORTRAN STATEMENTS:
            H2ORECOV = F1WATER/FEEDH2O

      SPECIFICATION:
        MAKE H2ORECOV APPROACH 0.98000
        WITHIN          0.00100000

      MANIPULATED VARIABLES:
        VARY     : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FLASH1
        LOWER LIMIT =        -100.000                    C
        UPPER LIMIT =         200.000                    C
        FINAL VALUE =          50.4573                   C

      VALUES OF ACCESSED FORTRAN VARIABLES:
        VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                         OF LOOP
        --------      --------------      -----------     -----
        F1WATER         410.815            436.301        KMOL/HR
        FEEDH2O         445.222            445.222        KMOL/HR
        H2ORECOV        MISSING           0.979964

    DESIGN-SPEC:  FLASH2
    --------------------

      SAMPLED VARIABLES:
        RECOV    : LOCAL-PARAM
        PENTOUT  : N-PEN-01MOLEFLOW IN STREAM FLASHLQ3 SUBSTREAM MIXED
        PENTIN   : N-PEN-01MOLEFLOW IN STREAM FLASHGAS SUBSTREAM MIXED

      FORTRAN STATEMENTS:
            RECOV = PENTOUT/PENTIN
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                                FLOWSHEET SECTION

    DESIGN-SPEC:  FLASH2 (CONTINUED)

      SPECIFICATION:
        MAKE RECOV APPROACH 0.98000
        WITHIN          0.00100000

      MANIPULATED VARIABLES:
        VARY     : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FLASH3
        LOWER LIMIT =        -100.000                    C
        UPPER LIMIT =         200.000                    C
```

```
      FINAL VALUE =         -59.6022                   C

    VALUES OF ACCESSED FORTRAN VARIABLES:
      VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                       OF LOOP
      --------      --------------      -----------     -----
      RECOV           MISSING           0.980319
      PENTOUT          3.34162           3.39560        KMOL/HR
      PENTIN           3.46377           3.46377        KMOL/HR

 TRANSFER BLOCK: HFUEL
 ---------------------
     EQUAL-TO : STREAM IN STREAM DIESEL
     SET      : STREAM IN STREAM DIESELHO

 TRANSFER BLOCK: MIDALK2
 -----------------------
     EQUAL-TO : STREAM IN STREAM MIDALK
     SET      : STREAM IN STREAM MIDALK2

 CONVERGENCE BLOCK:  $OLVER01
 ----------------------------
     Tear Stream  :  LIQ2WAMR
     Tolerance used:  0.100D-03
     Trace molefrac:  0.100D-05

     MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
     QMAX =   0.0     QMIN =  -5.0
     METHOD: WEGSTEIN      STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:   111
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                          *** FINAL VALUES ***

VAR#  TEAR STREAM VAR  STREAM   SUBSTREA COMPONEN ATTRIBUT ELEMENT      UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------  -------- -------- -------- -------- -------- -----------
------------   ------------   ------------
   1  TOTAL MOLEFLOW   LIQ2WAMR MIXED                                LBMOL/HR
   974.4112       974.4112         0.0
   2  MOLE-FLOW        LIQ2WAMR MIXED    WATER                      LBMOL/HR
   955.3736       955.3736         0.0
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                              FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER01 (CONTINUED)
   3  MOLE-FLOW        LIQ2WAMR MIXED    METHA-01                   LBMOL/HR
   8.5405-03      8.5405-03         0.0
   4  MOLE-FLOW        LIQ2WAMR MIXED    ETHAN-01                   LBMOL/HR
   5.2687-03      5.2687-03         0.0
   5  MOLE-FLOW        LIQ2WAMR MIXED    PROPA-01                   LBMOL/HR
   6.1310-02      6.1310-02         0.0
   6  MOLE-FLOW        LIQ2WAMR MIXED    N-BUT-01                   LBMOL/HR
   8.9026-02      8.9026-02         0.0
   7  MOLE-FLOW        LIQ2WAMR MIXED    N-PEN-01                   LBMOL/HR
   9.8640-04      9.8640-04         0.0
   8  MOLE-FLOW        LIQ2WAMR MIXED    N-HEX-01                   LBMOL/HR
   1.4452-02      1.4452-02         0.0
   9  MOLE-FLOW        LIQ2WAMR MIXED    N-HEP-01                   LBMOL/HR
   2.2319-03      2.2319-03         0.0
  10  MOLE-FLOW        LIQ2WAMR MIXED    N-OCT-01                   LBMOL/HR
  1.7257-04      1.7257-04         0.0
  11  MOLE-FLOW        LIQ2WAMR MIXED    N-NON-01                   LBMOL/HR
  0.4547         0.4547         0.0
  12  MOLE-FLOW        LIQ2WAMR MIXED    N-DEC-01                   LBMOL/HR
```

```
      1.0754-03      1.0754-03         0.0
9136  13  MOLE-FLOW        LIQ2WAMR MIXED    N-UND-01                    LBMOL/HR
      5.2257-04      5.2257-04         0.0
9137  14  MOLE-FLOW        LIQ2WAMR MIXED    N-DOD-01                    LBMOL/HR
      4.6746-04      4.6746-04         0.0
9138  15  MOLE-FLOW        LIQ2WAMR MIXED    N-TRI-01                    LBMOL/HR
      4.5646-04      4.5646-04         0.0
9139  16  MOLE-FLOW        LIQ2WAMR MIXED    N-TET-01                    LBMOL/HR
      4.4025-04      4.4025-04         0.0
9140  17  MOLE-FLOW        LIQ2WAMR MIXED    N-PEN-02                    LBMOL/HR
      6.4967-02      6.4967-02         0.0
9141  18  MOLE-FLOW        LIQ2WAMR MIXED    N-HEX-02                    LBMOL/HR
      3.6398-04      3.6398-04         0.0
9142  19  MOLE-FLOW        LIQ2WAMR MIXED    N-HEP-02                    LBMOL/HR
      0.1279         0.1279         0.0
9143  20  MOLE-FLOW        LIQ2WAMR MIXED    N-OCT-02                    LBMOL/HR
      0.1890         0.1890         0.0
9144  21  MOLE-FLOW        LIQ2WAMR MIXED    N-NON-02                    LBMOL/HR
      0.2657         0.2657         0.0
9145  22  MOLE-FLOW        LIQ2WAMR MIXED    N-EIC-01                    LBMOL/HR
      0.3432         0.3432         0.0
9146  23  MOLE-FLOW        LIQ2WAMR MIXED    N-HEN-01                    LBMOL/HR
      0.3987         0.3987         0.0
9147  24  MOLE-FLOW        LIQ2WAMR MIXED    N-DOC-01                    LBMOL/HR
      0.4195         0.4195         0.0
9148  25  MOLE-FLOW        LIQ2WAMR MIXED    N-TRI-02                    LBMOL/HR
      0.4354         0.4354         0.0
9149  26  MOLE-FLOW        LIQ2WAMR MIXED    N-TET-02                    LBMOL/HR
      0.4238         0.4238         0.0
9150  27  MOLE-FLOW        LIQ2WAMR MIXED    N-PEN-03                    LBMOL/HR
      0.3928         0.3928         0.0
9151  28  MOLE-FLOW        LIQ2WAMR MIXED    N-HEX-03                    LBMOL/HR
      0.3693         0.3693         0.0
9152  29  MOLE-FLOW        LIQ2WAMR MIXED    N-HEP-03                    LBMOL/HR
      0.3352         0.3352         0.0
9153  30  MOLE-FLOW        LIQ2WAMR MIXED    N-OCT-03                    LBMOL/HR
      0.3232         0.3232         0.0
9154  31  MOLE-FLOW        LIQ2WAMR MIXED    N-NON-03                    LBMOL/HR
      0.2656         0.2656         0.0
9155  32  MOLE-FLOW        LIQ2WAMR MIXED    N-TRI-03                    LBMOL/HR
      0.2357         0.2357         0.0
9156  33  MOLE-FLOW        LIQ2WAMR MIXED    PENTA-01                    LBMOL/HR
      0.0            0.0            0.0
9157  34  MOLE-FLOW        LIQ2WAMR MIXED    CARBO-01                    LBMOL/HR
      8.1724-03      8.1724-03         0.0
9158  35  MOLE-FLOW        LIQ2WAMR MIXED    HYDRO-01                    LBMOL/HR
      1.9214         1.9214         0.0
9159  36  MOLE-FLOW        LIQ2WAMR MIXED    CARBO-02                    LBMOL/HR
      11.8779        11.8779         0.0
9160  37  PRESSURE         LIQ2WAMR MIXED                                PSIA
      363.0000       363.0000         0.0
9161  38  MASS ENTHALPY    LIQ2WAMR MIXED                                BTU/LB
      -6072.1219     -6072.1216     -5.1346-04
9162
9163                          *** ITERATION HISTORY ***
9164
9165     TEAR STREAMS AND TEAR VARIABLES:
9166
9167     ITERATION   MAX-ERR/TOL VAR#  STREAM ID      VARIABLE         SUBSTREA COMPONEN
         ATTRIBUT ELEMENT
9168     ---------   ----------- ----  ---------      ---------------- -------- --------
         -------- -------
9169          1     -0.5135E-03    38  LIQ2WAMR       MASS ENTHALPY
              MIXED
9170
9171  CONVERGENCE BLOCK:  $OLVER02
```

```
 ----------------------------
     SPECS: FLAS1H2O
     MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
                 MAX-STEP=       100.    % OF RANGE
                 XTOL=       1.000000E-08
     THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 6

                               FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER02 (CONTINUED)
     METHOD: SECANT        STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:     6
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     0

                          *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                              UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- -------------------------                      -----------
------------   ------------   ------------
   1  BLOCK-VAR        FLASH1.PARAM.TEMP                              C
   50.4573        49.0847     -3.6335-02

                          *** ITERATION HISTORY ***

     DESIGN-SPEC ID:
     FLAS1H2O

     ITERATED:  SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FLASH1

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1      80.00          -0.5728E-01     -57.28
          2      83.00          -0.6747E-01     -67.47
          3      63.13          -0.1691E-01     -16.91
          4      56.49          -0.6966E-02     -6.966
          5      49.08           0.1312E-02      1.312
          6      50.46          -0.3633E-04    -0.3633E-01

 CONVERGENCE BLOCK:  $OLVER03
 ----------------------------
     SPECS: FLASH2
     MAXIT=   30 STEP-SIZE=    1.0000    % OF RANGE
                 MAX-STEP=       100.    % OF RANGE
                 XTOL=       1.000000E-08
     THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
     METHOD: SECANT        STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:     4
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     0

                          *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION                              UNIT
VALUE       PREV VALUE       ERR/TOL
----  ---------------- -------------------------                      -----------
------------   ------------   ------------
   1  BLOCK-VAR        FLASH3.PARAM.TEMP                              C
   -59.6022       -57.8454         0.3186

                          *** ITERATION HISTORY ***
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 7

                               FLOWSHEET SECTION
```

CONVERGENCE BLOCK: $OLVER03 (CONTINUED)

DESIGN-SPEC ID:
FLASH2

ITERATED: SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK FLASH3

ITERATION	VARIABLE	ERROR	ERR/TOL
1	-54.00	-0.1526E-01	-15.26
2	-51.00	-0.2717E-01	-27.17
3	-57.85	-0.3809E-02	-3.809
4	-59.60	0.3186E-03	0.3186

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:
$OLVER02 FLASH1
(RETURN $OLVER02)
COOLER1
$OLVER03 FLASH3
(RETURN $OLVER03)
LIQFLAH DECANT1
$OLVER01 DECANTH DECANT2 LUBEHEAT FLASHLUB MIDALK2 MIXER DIST1 FUELHEAT
| FLASH4 HFUEL LIQ2HX1 LUBEHX
(RETURN $OLVER01)

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
WATER	981.584	981.579	0.486405E-05
METHA-01	15.2201	15.2201	-0.127327E-05
ETHAN-01	13.2201	13.2202	-0.127549E-05
PROPA-01	11.4802	11.4802	-0.118660E-05
N-BUT-01	10.0003	10.0003	-0.999689E-06
N-PEN-01	8.80505	8.80506	-0.519044E-06
N-HEX-01	7.81564	7.81564	0.548099E-06
N-HEP-01	7.00159	7.00158	0.254813E-05
N-OCT-01	6.27652	6.27649	0.401181E-05
N-NON-01	5.74981	5.74979	0.386648E-05
N-DEC-01	5.51212	5.51209	0.379789E-05
N-UND-01	5.17477	5.17475	0.357321E-05
N-DOD-01	4.98003	4.98001	0.327628E-05
N-TRI-01	4.70065	4.70064	0.301850E-05
N-TET-01	4.30107	4.30106	0.287469E-05
N-PEN-02	3.88388	3.88387	0.277457E-05
N-HEX-02	3.56613	3.56612	0.261649E-05
N-HEP-02	3.00633	3.00632	0.267194E-05
N-OCT-02	2.62469	2.62468	0.271822E-05
N-NON-02	2.17354	2.17354	0.282331E-05
N-EIC-01	1.80746	1.80745	0.298116E-05

FLOWSHEET SECTION

OVERALL FLOWSHEET BALANCE (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
CONVENTIONAL COMPONENTS (LBMOL/HR)			
N-HEN-01	1.49715	1.49715	0.316593E-05

N-DOC-01	1.15874	1.15873	0.340176E-05
N-TRI-02	0.983877	0.983873	0.360077E-05
N-TET-02	0.815857	0.815853	0.379201E-05
N-PEN-03	0.687083	0.687081	0.392180E-05
N-HEX-03	0.570596	0.570593	0.411033E-05
N-HEP-03	0.484769	0.484766	0.422047E-05
N-OCT-03	0.376824	0.376822	0.463504E-05
N-NON-03	0.354359	0.354357	0.436551E-05
N-TRI-03	0.304317	0.304315	0.442746E-05
PENTA-01	0.00000	0.00000	0.00000
CARBO-01	1.19001	1.19001	-0.125528E-05
HYDRO-01	3560.70	3560.71	-0.129670E-05
CARBO-02	395.903	395.904	-0.800871E-06
TOTAL BALANCE			
MOLE(LBMOL/HR)	5073.91	5073.91	0.179249E-15
MASS(LB/HR)	58249.7	58249.6	0.176157E-05
ENTHALPY(BTU/HR)	-0.194403E+09	-0.197383E+09	0.150948E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	23527.9	LB/HR
PRODUCT STREAMS CO2E	23528.0	LB/HR
NET STREAMS CO2E PRODUCTION	0.217265E-01	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.217265E-01	LB/HR

PHYSICAL PROPERTIES SECTION

COMPONENTS

ID	TYPE	ALIAS	NAME
WATER	C	H2O	WATER
METHA-01	C	CH4	METHANE
ETHAN-01	C	C2H6	ETHANE
PROPA-01	C	C3H8	PROPANE
N-BUT-01	C	C4H10-1	N-BUTANE
N-PEN-01	C	C5H12-1	N-PENTANE
N-HEX-01	C	C6H14-1	N-HEXANE
N-HEP-01	C	C7H16-1	N-HEPTANE
N-OCT-01	C	C8H18-1	N-OCTANE
N-NON-01	C	C9H20-1	N-NONANE
N-DEC-01	C	C10H22-1	N-DECANE
N-UND-01	C	C11H24	N-UNDECANE
N-DOD-01	C	C12H26	N-DODECANE
N-TRI-01	C	C13H28	N-TRIDECANE
N-TET-01	C	C14H30	N-TETRADECANE
N-PEN-02	C	C15H32	N-PENTADECANE
N-HEX-02	C	C16H34	N-HEXADECANE
N-HEP-02	C	C17H36	N-HEPTADECANE
N-OCT-02	C	C18H38	N-OCTADECANE
N-NON-02	C	C19H40	N-NONADECANE
N-EIC-01	C	C20H42	N-EICOSANE
N-HEN-01	C	C21H44	N-HENEICOSANE
N-DOC-01	C	C22H46	N-DOCOSANE
N-TRI-02	C	C23H48	N-TRICOSANE
N-TET-02	C	C24H50	N-TETRACOSANE
N-PEN-03	C	C25H52	N-PENTACOSANE
N-HEX-03	C	C26H54	N-HEXACOSANE
N-HEP-03	C	C27H56	N-HEPTACOSANE
N-OCT-03	C	C28H58	N-OCTACOSANE
N-NON-03	C	C29H60	N-NONACOSANE
N-TRI-03	C	C30H62	N-TRIACONTANE
PENTA-01	C	C50H102	PENTACONTANE
CARBO-01	C	CO	CARBON-MONOXIDE
HYDRO-01	C	H2	HYDROGEN

U-O-S BLOCK SECTION

BLOCK: COOLER1 MODEL: HEATER

INLET STREAM: FLASHGAS
OUTLET STREAM: COLDFLAS
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	4009.66	4009.66	0.00000
MASS(LB/HR)	26686.6	26686.6	0.219479E-13
ENTHALPY(BTU/HR)	-0.655711E+08	-0.719663E+08	0.888632E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	22118.6	LB/HR
PRODUCT STREAMS CO2E	22118.6	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH		
SPECIFIED TEMPERATURE	C	-54.0000
SPECIFIED PRESSURE	PSIA	363.000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	-54.000
OUTLET PRESSURE	PSIA	363.00
HEAT DUTY	BTU/HR	-0.63952E+07
OUTLET VAPOR FRACTION		0.97961

U-O-S BLOCK SECTION

BLOCK: COOLER1 MODEL: HEATER (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	0.49036E-02	0.24048	0.10707E-05	0.44522E-05
METHA-01	0.37796E-02	0.15794E-01	0.35296E-02	0.22348
ETHAN-01	0.32841E-02	0.88272E-02	0.31687E-02	0.35897
PROPA-01	0.28114E-02	0.74382E-01	0.13220E-02	0.17772E-01
N-BUT-01	0.23749E-02	0.90584E-01	0.53916E-03	0.59520E-02
N-PEN-01	0.19045E-02	0.89912E-01	0.72958E-04	0.81144E-03
N-HEX-01	0.13279E-02	0.64634E-01	0.10423E-04	0.16125E-03
N-HEP-01	0.59846E-03	0.29342E-01	0.28421E-06	0.96859E-05
N-OCT-01	0.13536E-03	0.66378E-02	0.36357E-07	0.54772E-05
N-NON-01	0.10584E-03	0.51914E-02	0.14253E-08	0.27455E-06
N-DEC-01	0.28676E-04	0.14066E-02	0.14170E-09	0.10074E-06
N-UND-01	0.12793E-04	0.62752E-03	0.27085E-11	0.43162E-08
N-DOD-01	0.40417E-05	0.19825E-03	0.11640E-12	0.58714E-09
N-TRI-01	0.13195E-05	0.64725E-04	0.96142E-14	0.14854E-09
N-TET-01	0.45811E-06	0.22471E-04	0.54566E-15	0.24283E-10
N-PEN-02	0.66406E-07	0.32574E-05	0.10400E-16	0.31926E-11

N-HEX-02	0.40223E-07	0.19730E-05	0.14671E-17	0.74358E-12
N-HEP-02	0.39671E-08	0.19459E-06	0.16165E-19	0.83069E-13
N-OCT-02	0.11320E-08	0.55525E-07	0.88168E-21	0.15879E-13
N-NON-02	0.28506E-09	0.13982E-07	0.29703E-22	0.21243E-14
N-EIC-01	0.77271E-10	0.37903E-08	0.11808E-23	0.31153E-15
N-HEN-01	0.25971E-10	0.12739E-08	0.14133E-24	0.11094E-15
N-DOC-01	0.73268E-11	0.35939E-09	0.49321E-26	0.13723E-16
N-TRI-02	0.21001E-11	0.10301E-09	0.16504E-27	0.16021E-17
N-TET-02	0.84945E-12	0.41667E-10	0.28091E-28	0.67418E-18
N-PEN-03	0.27345E-12	0.13413E-10	0.22877E-29	0.17056E-18
N-HEX-03	0.10533E-12	0.51666E-11	0.28012E-30	0.54218E-19
N-HEP-03	0.32325E-13	0.15856E-11	0.15802E-31	0.99657E-20
N-OCT-03	0.57663E-14	0.28285E-12	0.40169E-34	0.14202E-21
N-NON-03	0.24403E-14	0.11970E-12	0.80472E-35	0.67226E-22
CARBO-01	0.29466E-03	0.34795E-04	0.30007E-03	8.6239
HYDRO-01	0.88753	0.29569E-02	0.90594	306.38
CARBO-02	0.90899E-01	0.36890	0.85114E-01	0.23073

BLOCK: DECANT1 MODEL: DECANTER

INLET STREAM: FLASHWRM
FIRST LIQUID OUTLET: LIQ1COLD
SECOND LIQUID OUTLET: LIQ2
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	1044.73	1044.73	0.00000
MASS(LB/HR)	27515.9	27515.9	-0.132214E-14
ENTHALPY(BTU/HR)	-0.126958E+09	-0.126930E+09	-0.216988E-03

U-O-S BLOCK SECTION

BLOCK: DECANT1 MODEL: DECANTER (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	1409.26	LB/HR
PRODUCT STREAMS CO2E	1409.26	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

LIQUID-LIQUID SPLIT, TP SPECIFICATION

SPECIFIED TEMPERATURE	C	120.000
SPECIFIED PRESSURE DROP	PSI	0.0
CONVERGENCE TOLERANCE ON EQUILIBRIUM		0.10000E-01
MAXIMUM NO ITERATIONS ON EQUILIBRIUM		200
EQUILIBRIUM METHOD	GIBBS ENERGY MINIMIZATION	
KLL COEFFICIENTS FROM	OPTION SET OR EOS	
KLL BASIS		MOLE
KEY COMPONENT(S):	WATER	

U-O-S BLOCK SECTION

BLOCK: DECANT1 MODEL: DECANTER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	C	120.00
OUTLET PRESSURE	PSIA	363.00
CALCULATED HEAT DUTY	BTU/HR	27548.

MOLAR RATIO 1ST LIQUID / TOTAL LIQUID 0.67307E-01

L1-L2 PHASE EQUILIBRIUM :

COMP	F	X1	X2	K
WATER	0.92070	0.092517	0.98046	10.5976
METHA-01	0.624130-04	0.00080583	0.876473-05	0.010877
ETHAN-01	0.497374-04	0.00066403	0.540704-05	0.0081427
PROPA-01	0.00019840	0.0020758	0.629199-04	0.030312
N-BUT-01	0.00045721	0.0055268	0.913637-04	0.016531
N-PEN-01	0.0010278	0.015256	0.101230-05	0.663545-04
N-HEX-01	0.0021495	0.031730	0.148316-04	0.00046742
N-HEP-01	0.0040205	0.059702	0.229055-05	0.383662-04
N-OCT-01	0.0049652	0.073766	0.177097-06	0.240079-05
N-NON-01	0.0043702	0.058462	0.00046663	0.0079818
N-DEC-01	0.0040441	0.060069	0.110362-05	0.183724-04
N-UND-01	0.0035595	0.052877	0.536298-06	0.101424-04
N-DOD-01	0.0031336	0.046550	0.479735-06	0.103057-04
N-TRI-01	0.0027229	0.040448	0.468451-06	0.115814-04
N-TET-01	0.0023721	0.035236	0.451816-06	0.128226-04
N-PEN-02	0.0020673	0.029790	0.666727-04	0.0022381
N-HEX-02	0.0017898	0.026586	0.373539-06	0.140502-04
N-HEP-02	0.0015411	0.021076	0.00013129	0.0062294
N-OCT-02	0.0013688	0.017648	0.00019398	0.010991
N-NON-02	0.0011773	0.013714	0.00027263	0.019880
N-EIC-01	0.0010338	0.010478	0.00035223	0.033616
N-HEN-01	0.00090933	0.0078400	0.00040917	0.052190
N-DOC-01	0.00075618	0.0052685	0.00043055	0.081722
N-TRI-02	0.00067960	0.0039053	0.00044682	0.11442
N-TET-02	0.00059346	0.0027898	0.00043496	0.15591
N-PEN-03	0.00051688	0.0020937	0.00040309	0.19253
N-HEX-03	0.00044988	0.0014314	0.00037905	0.26481
N-HEP-03	0.00039245	0.0010636	0.00034401	0.32344
N-OCT-03	0.00033502	0.00038151	0.00033166	0.86933
N-NON-03	0.00029673	0.00063089	0.00027261	0.43211
N-TRI-03	0.00025844	0.00048803	0.00024187	0.49561
CARBO-01	0.813933-05	0.470732-05	0.838700-05	1.78169
HYDRO-01	0.0019137	0.0011081	0.0019718	1.77943
CARBO-02	0.030082	0.27801	0.012190	0.043846

U-O-S BLOCK SECTION

BLOCK: DECANT2 MODEL: DECANTER

INLET STREAM: LIQ2HOT
FIRST LIQUID OUTLET: HYDROCAR
SECOND LIQUID OUTLET: WATEROUT
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	974.411	974.411	0.350017E-15
MASS(LB/HR)	19338.6	19338.6	-0.126843E-09
ENTHALPY(BTU/HR)	-0.114481E+09	-0.114515E+09	0.297608E-03

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	526.170	LB/HR
PRODUCT STREAMS CO2E	526.170	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

LIQUID-LIQUID SPLIT, TP SPECIFICATION

```
   SPECIFIED TEMPERATURE              C                        195.000
   SPECIFIED PRESSURE                 PSIA                   362.594
   CONVERGENCE TOLERANCE ON EQUILIBRIUM                       0.10000E-03
   MAXIMUM NO ITERATIONS ON EQUILIBRIUM                       30
   EQUILIBRIUM METHOD                            EQUATION-SOLVING
   KLL COEFFICIENTS FROM                        OPTION SET OR EOS
   KLL BASIS                                                 MOLE
   KEY COMPONENT(S):       WATER
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 15

                              U-O-S BLOCK SECTION

 BLOCK:  DECANT2  MODEL: DECANTER (CONTINUED)

                              ***  RESULTS  ***

   OUTLET TEMPERATURE      C                                  195.00
   OUTLET PRESSURE         PSIA                               362.59
   CALCULATED HEAT DUTY    BTU/HR                            -34081.
   MOLAR RATIO 1ST LIQUID / TOTAL LIQUID                     0.81489E-04

   L1-L2 PHASE EQUILIBRIUM :
      COMP          F             X1            X2            K
      WATER      0.98046       0.056164      0.98054       17.4585
      METHA-01   0.876473-05   0.436637-04   0.876189-05   0.20067
      ETHAN-01   0.540704-05   0.00094268    0.533065-05   0.0056548
      PROPA-01   0.629199-04   0.0016974     0.627867-04   0.036990
      N-BUT-01   0.913637-04   0.0053048     0.909388-04   0.017143
      N-PEN-01   0.101230-05   0.0069798     0.443561-06   0.635489-04
      N-HEX-01   0.148316-04   0.019441      0.132484-04   0.00068148
      N-HEP-01   0.229055-05   0.012198      0.129664-05   0.00010630
      N-OCT-01   0.177097-06   0.00019221    0.161448-06   0.00083995
      N-NON-01   0.00046663    0.040663      0.00046336    0.011395
      N-DEC-01   0.110362-05   0.0067749     0.551585-06   0.814162-04
      N-UND-01   0.536298-06   0.0058391     0.604869-07   0.103590-04
      N-DOD-01   0.479735-06   0.0051061     0.636541-07   0.124664-04
      N-TRI-01   0.468451-06   0.0048191     0.757525-07   0.157191-04
      N-TET-01   0.451816-06   0.0043869     0.943379-07   0.215042-04
      N-PEN-02   0.666727-04   0.10554       0.580769-04   0.00055027
      N-HEX-02   0.373539-06   0.0033798     0.981317-07   0.290348-04
      N-HEP-02   0.00013129    0.13016       0.00012070    0.00092726
      N-OCT-02   0.00019398    0.13578       0.00018293    0.0013472
      N-NON-02   0.00027263    0.12592       0.00026240    0.0020838
      N-EIC-01   0.00035223    0.10166       0.00034397    0.0033834
      N-HEN-01   0.00040917    0.076315      0.00040299    0.0052806
      N-DOC-01   0.00043055    0.048976      0.00042659    0.0087104
      N-TRI-02   0.00044682    0.032924      0.00044418    0.013491
      N-TET-02   0.00043496    0.020639      0.00043331    0.020995
      N-PEN-03   0.00040309    0.012770      0.00040209    0.031487
      N-HEX-03   0.00037905    0.0081661     0.00037841    0.046339
      N-HEP-03   0.00034401    0.0052506     0.00034361    0.065443
      N-OCT-03   0.00033166    0.00034301    0.00033166    0.96690
      N-NON-03   0.00027261    0.0023540     0.00027244    0.11574
      N-TRI-03   0.00024187    0.0021800     0.00024171    0.11088
      CARBO-01   0.838700-05   0.715341-05   0.838710-05   1.17246
      HYDRO-01   0.0019718     0.0016847     0.0019719     1.17044
      CARBO-02   0.012190      0.015391      0.012190      0.79197

 BLOCK:  DECANTH  MODEL: HEATER
 ------------------------------
   INLET STREAM:          LIQ2WAMR
   OUTLET STREAM:         LIQ2HOT
   PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 16

                              U-O-S BLOCK SECTION
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BLOCK: DECANTH MODEL: HEATER (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	974.411	974.411	0.00000
MASS(LB/HR)	19338.6	19338.6	0.00000
ENTHALPY(BTU/HR)	-0.117427E+09	-0.114481E+09	-0.250819E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	526.170	LB/HR
PRODUCT STREAMS CO2E	526.170	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH		
SPECIFIED TEMPERATURE	C	195.000
SPECIFIED PRESSURE	PSIA	363.000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	195.00
OUTLET PRESSURE	PSIA	363.00
HEAT DUTY	BTU/HR	0.29453E+07
OUTLET VAPOR FRACTION		0.46545E-02

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	0.98046	0.98245	0.55500	0.56491
METHA-01	0.87647E-05	0.42389E-05	0.97658E-03	230.38
ETHAN-01	0.54070E-05	0.47882E-06	0.10593E-02	2212.3
PROPA-01	0.62920E-04	0.35006E-04	0.60321E-02	172.31
N-BUT-01	0.91364E-04	0.52154E-04	0.84761E-02	162.52
N-PEN-01	0.10123E-05	0.15574E-07	0.21416E-03	13751.
N-HEX-01	0.14832E-04	0.28807E-05	0.25705E-02	892.31
N-HEP-01	0.22906E-05	0.18186E-06	0.45322E-03	2492.1
N-OCT-01	0.17710E-06	0.17451E-06	0.73125E-06	4.1904
N-NON-01	0.46663E-03	0.44706E-03	0.46522E-02	10.406
N-DEC-01	0.11036E-05	0.33075E-06	0.16638E-03	503.04
N-UND-01	0.53630E-06	0.22187E-07	0.11048E-03	4979.3

U-O-S BLOCK SECTION

BLOCK: DECANTH MODEL: HEATER (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
N-DOD-01	0.47974E-06	0.39061E-07	0.94716E-04	2424.8
N-TRI-01	0.46845E-06	0.74349E-07	0.84745E-04	1139.8
N-TET-01	0.45182E-06	0.11078E-06	0.73381E-04	662.40
N-PEN-02	0.66673E-04	0.63298E-04	0.78833E-03	12.454
N-HEX-02	0.37354E-06	0.21128E-06	0.35072E-04	166.00
N-HEP-02	0.13129E-03	0.13016E-03	0.37391E-03	2.8727
N-OCT-02	0.19398E-03	0.19374E-03	0.24488E-03	1.2640
N-NON-02	0.27263E-03	0.27324E-03	0.14244E-03	0.52129

N-EIC-01	0.35223E-03	0.35355E-03	0.69444E-04	0.19642
N-HEN-01	0.40917E-03	0.41094E-03	0.32207E-04	0.78374E-01
N-DOC-01	0.43055E-03	0.43250E-03	0.13240E-04	0.30612E-01
N-TRI-02	0.44682E-03	0.44889E-03	0.52503E-05	0.11696E-01
N-TET-02	0.43496E-03	0.43698E-03	0.20744E-05	0.47471E-02
N-PEN-03	0.40309E-03	0.40497E-03	0.78055E-06	0.19274E-02
N-HEX-03	0.37905E-03	0.38082E-03	0.30832E-06	0.80962E-03
N-HEP-03	0.34401E-03	0.34562E-03	0.11454E-06	0.33141E-03
N-OCT-03	0.33166E-03	0.33321E-03	0.38060E-08	0.11422E-04
N-NON-03	0.27261E-03	0.27389E-03	0.22720E-07	0.82953E-04
N-TRI-03	0.24187E-03	0.24300E-03	0.93293E-08	0.38392E-04
CARBO-01	0.83870E-05	0.69293E-05	0.32010E-03	46.195
HYDRO-01	0.19718E-02	0.85703E-03	0.24037	280.47
CARBO-02	0.12190E-01	0.11416E-01	0.17764	15.560

BLOCK: DIST1 MODEL: RADFRAC

INLETS - COL1FEED STAGE 7
OUTLETS - GASES STAGE 1
FLASHFE STAGE 11
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	168.008	168.008	0.169169E-15
MASS(LB/HR)	12659.8	12659.8	-0.143683E-15
ENTHALPY(BTU/HR)	-0.220308E+08	-0.221136E+08	0.374131E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	3627.21	LB/HR
PRODUCT STREAMS CO2E	3627.21	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

****
**** INPUT DATA ****
****

**** INPUT PARAMETERS ****

NUMBER OF STAGES	11
ALGORITHM OPTION	SUM-RATES
ABSORBER OPTION	NO
INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	SCHUBERT
DESIGN SPECIFICATION METHOD	SIMULT
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	200
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	1.00000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST	1.00000
MOLAR REFLUX RATIO	5.77000

DISTILLATE TO FEED RATIO 0.50000

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 14.7000

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS	
COMPONENT:	GASES	FLASHFE
WATER	.27491E-02	.99725
METHA-01	1.0000	.11388E-13
ETHAN-01	1.0000	.34731E-07
PROPA-01	1.0000	.51264E-06

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS	
COMPONENT:	GASES	FLASHFE
N-BUT-01	.99940	.59634E-03
N-PEN-01	.23290	.76710
N-HEX-01	.42273E-06	1.0000
N-HEP-01	.25067E-11	1.0000
N-OCT-01	.95603E-13	1.0000
N-NON-01	0.0000	1.0000
N-DEC-01	0.0000	1.0000
N-UND-01	0.0000	1.0000
N-DOD-01	0.0000	1.0000
N-TRI-01	0.0000	1.0000
N-TET-01	0.0000	1.0000
N-PEN-02	0.0000	1.0000
N-HEX-02	0.0000	1.0000
N-HEP-02	0.0000	1.0000
N-OCT-02	0.0000	1.0000
N-NON-02	0.0000	1.0000
N-EIC-01	0.0000	1.0000
N-HEN-01	0.0000	1.0000
N-DOC-01	0.0000	1.0000
N-TRI-02	0.0000	1.0000
N-TET-02	0.0000	1.0000
N-PEN-03	0.0000	1.0000
N-HEX-03	0.0000	1.0000
N-HEP-03	0.0000	1.0000
N-OCT-03	0.0000	1.0000
N-NON-03	0.0000	1.0000
N-TRI-03	0.0000	1.0000
CARBO-01	1.0000	.20757E-11
HYDRO-01	1.0000	0.0000
CARBO-02	1.0000	.21027E-06

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	C		-27.8774
BOTTOM STAGE TEMPERATURE	C		63.1728
TOP STAGE LIQUID FLOW	LBMOL/HR		484.259
BOTTOM STAGE LIQUID FLOW	LBMOL/HR		84.0039
TOP STAGE VAPOR FLOW	LBMOL/HR		84.0036
BOILUP VAPOR FLOW	LBMOL/HR		426.568
MOLAR REFLUX RATIO			5.76474
MOLAR BOILUP RATIO			5.07795
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-6,661,460.	
REBOILER DUTY	BTU/HR	7,100,580.	

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT	0.54107	STAGE= 4	
BUBBLE POINT	0.32720	STAGE= 1	
COMPONENT MASS BALANCE	0.89170E-15	STAGE= 9	COMP=N-NON-02
ENERGY BALANCE	0.28444	STAGE= 6	

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE C	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	-27.877	14.700	-74733.	-0.13923E+06	-.66615+07
2	18.196	14.700	-73483.	-72545.	
3	26.001	14.700	-74003.	-71900.	
4	19.742	14.700	-75114.	-72429.	
5	-16.921	14.700	-80080.	-75645.	
6	9.2202	14.700	-82783.	-90003.	
7	23.587	14.700	-94396.	-82122.	
8	28.861	14.700	-92399.	-75526.	
9	29.685	14.700	-87101.	-74588.	
10	35.539	14.700	-0.10296E+06	-68821.	
11	63.173	14.700	-0.12402E+06	-82172.	.71006+07

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	484.3	84.00					84.0035
2	556.3	568.3					
3	593.3	640.3					
4	523.7	677.3					
5	175.9	607.7					
6	394.8	259.9					
7	587.6	478.8			168.0075		
8	678.9	503.6					
9	620.3	594.9					
10	510.6	536.3					
11	84.00	426.6				84.0039	

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR LIQUID	FLOW RATE LB/HR VAPOR	FEED RATE LB/HR LIQUID	FEED RATE LB/HR VAPOR	FEED RATE LB/HR MIXED	PRODUCT RATE LB/HR LIQUID	PRODUCT RATE LB/HR VAPOR
1	0.3157E+05	3782.					3782.0948
2	0.3894E+05	0.3535E+05					
3	0.4240E+05	0.4272E+05					
4	0.3755E+05	0.4618E+05					
5	0.1228E+05	0.4134E+05					
6	0.2535E+05	0.1606E+05					
7	0.3722E+05	0.2913E+05			.12660+05		
8	0.4294E+05	0.2834E+05					
9	0.4462E+05	0.3406E+05					
10	0.3124E+05	0.3575E+05					
11	8878.	0.2236E+05				8877.6717	

**** MOLE-X-PROFILE ****

STAGE	WATER	METHA-01	ETHAN-01	PROPA-01	N-BUT-01
1	0.25034E-02	0.13820E-03	0.83685E-03	0.69998E-01	0.31123
2	0.91968E-04	0.19199E-04	0.89002E-04	0.12129E-01	0.12461
3	0.12271E-04	0.15176E-04	0.53736E-04	0.26486E-02	0.40360E-01
4	0.21777E-03	0.10245E-04	0.99019E-04	0.16475E-02	0.17280E-01
5	0.17114E-01	0.94967E-04	0.21192E-03	0.41764E-02	0.41684E-01
6	0.12897	0.23328E-04	0.29127E-03	0.51667E-02	0.29006E-01
7	0.28932	0.12249E-04	0.12785E-03	0.20005E-02	0.14434E-01
8	0.28410	0.34341E-07	0.78366E-05	0.21315E-03	0.52380E-02
9	0.15404	0.98857E-10	0.45509E-06	0.22873E-04	0.19388E-02
10	0.41935	0.20427E-12	0.17951E-07	0.14312E-05	0.51509E-03
11	0.31068	0.29620E-15	0.38740E-09	0.46225E-07	0.59645E-04

**** MOLE-X-PROFILE ****

STAGE	N-PEN-01	N-HEX-01	N-HEP-01	N-OCT-01	N-NON-01
1	0.59905	0.69977E-05	0.47224E-09	0.30077E-10	0.91049E-14
2	0.86122	0.34757E-04	0.10736E-07	0.99928E-09	0.10753E-11
3	0.95533	0.12110E-03	0.13313E-06	0.20005E-07	0.73194E-10
4	0.97521	0.49735E-03	0.23157E-05	0.58886E-06	0.78294E-08
5	0.90935	0.15244E-02	0.36791E-04	0.97870E-05	0.60658E-06
6	0.80934	0.66310E-02	0.85945E-03	0.40325E-03	0.95951E-04
7	0.59018	0.20317E-01	0.11797E-01	0.10020E-01	0.77799E-02
8	0.61222	0.32063E-01	0.10517E-01	0.87646E-02	0.67499E-02
9	0.67514	0.91309E-01	0.15500E-01	0.10890E-01	0.76399E-02
10	0.30869	0.13806	0.41454E-01	0.23909E-01	0.13423E-01
11	0.78158E-01	0.89699E-01	0.78538E-01	0.68208E-01	0.53994E-01

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MOLE-X-PROFILE ****

STAGE	N-DEC-01	N-UND-01	N-DOD-01	N-TRI-01	N-TET-01
1	0.82111E-17	0.21854E-20	0.20486E-23	0.29782E-26	0.34718E-29
2	0.23895E-14	0.21789E-17	0.66416E-20	0.23758E-22	0.83592E-25
3	0.37801E-12	0.11234E-14	0.93524E-17	0.87204E-19	0.81453E-21
4	0.12867E-09	0.14562E-11	0.37907E-13	0.10786E-14	0.30717E-16
5	0.35147E-07	0.20700E-08	0.15673E-09	0.12960E-10	0.10560E-11
6	0.24395E-04	0.59858E-05	0.16314E-05	0.46584E-06	0.13243E-06
7	0.74014E-02	0.64189E-02	0.55990E-02	0.48494E-02	0.42196E-02
8	0.64116E-02	0.55576E-02	0.48470E-02	0.41979E-02	0.36526E-02
9	0.70474E-02	0.60904E-02	0.53070E-02	0.45951E-02	0.39979E-02
10	0.96899E-02	0.78125E-02	0.65836E-02	0.56260E-02	0.48745E-02
11	0.51652E-01	0.44873E-01	0.39160E-01	0.33922E-01	0.29517E-01

**** MOLE-X-PROFILE ****

STAGE	N-PEN-02	N-HEX-02	N-HEP-02	N-OCT-02	N-NON-02

1	0.21436E-33	0.40744E-35	0.25644E-39	0.13281E-42	0.31480E-45
2	0.12530E-28	0.78074E-30	0.11939E-33	0.19020E-36	0.11569E-38
3	0.30774E-24	0.55946E-25	0.20581E-28	0.98011E-31	0.13749E-32
4	0.47384E-19	0.20568E-19	0.30552E-22	0.51013E-24	0.19652E-25
5	0.31444E-13	0.60629E-14	0.17326E-15	0.10585E-16	0.91084E-18
6	0.24335E-07	0.95940E-08	0.17110E-08	0.41097E-09	0.11393E-09
7	0.35654E-02	0.31816E-02	0.25222E-02	0.21119E-02	0.16411E-02
8	0.30863E-02	0.27540E-02	0.21833E-02	0.18281E-02	0.14206E-02
9	0.33779E-02	0.30143E-02	0.23896E-02	0.20009E-02	0.15548E-02
10	0.41076E-02	0.36636E-02	0.29034E-02	0.24309E-02	0.18889E-02
11	0.24942E-01	0.22257E-01	0.17644E-01	0.14774E-01	0.11480E-01

**** MOLE-X-PROFILE ****

STAGE	N-EIC-01	N-HEN-01	N-DOC-01	N-TRI-02	N-TET-02
1	0.28959E-48	0.11277E-50	0.10722E-53	0.21387E-58	0.72181E-60
2	0.30559E-41	0.28180E-43	0.74855E-46	0.66859E-50	0.43480E-51
3	0.96998E-35	0.20748E-36	0.14306E-38	0.55819E-42	0.66257E-43
4	0.43904E-27	0.22686E-28	0.48158E-30	0.10981E-32	0.23090E-33
5	0.58871E-19	0.72828E-20	0.43272E-21	0.77693E-23	0.18062E-23
6	0.26914E-10	0.82443E-11	0.17589E-11	0.22960E-12	0.94319E-13
7	0.12539E-02	0.93818E-03	0.63044E-03	0.46731E-03	0.33383E-03
8	0.10854E-02	0.81211E-03	0.54573E-03	0.40452E-03	0.28897E-03
9	0.11879E-02	0.88883E-03	0.59728E-03	0.44273E-03	0.31627E-03
10	0.14432E-02	0.10798E-02	0.72562E-03	0.53786E-03	0.38422E-03
11	0.87713E-02	0.65630E-02	0.44103E-02	0.32691E-02	0.23353E-02

**** MOLE-X-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
1	0.88236E-62	0.40222E-64	0.39643E-67	0.15854E-74	0.37157E-74
2	0.10365E-52	0.10674E-54	0.30286E-57	0.21511E-64	0.32164E-63
3	0.28993E-44	0.65535E-46	0.50923E-48	0.50936E-55	0.50243E-53
4	0.19837E-34	0.10556E-35	0.25335E-37	0.69802E-43	0.37442E-41
5	0.29933E-24	0.35930E-25	0.24716E-26	0.48108E-30	0.40591E-29
6	0.32947E-13	0.99000E-14	0.23468E-14	0.27766E-16	0.89314E-16
7	0.25053E-03	0.17128E-03	0.12727E-03	0.45652E-04	0.75493E-04
8	0.21686E-03	0.14826E-03	0.11017E-03	0.39517E-04	0.65348E-04
9	0.23735E-03	0.16227E-03	0.12058E-03	0.43251E-04	0.71522E-04
10	0.28835E-03	0.19714E-03	0.14648E-03	0.52544E-04	0.86889E-04

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MOLE-X-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
11	0.17526E-02	0.11982E-02	0.89033E-03	0.31936E-03	0.52811E-03

**** MOLE-X-PROFILE ****

STAGE	N-TRI-03	CARBO-01	HYDRO-01	CARBO-02
1	0.11361E-79	0.37165E-07	0.11060E-06	0.16241E-01
2	0.64515E-68	0.15326E-07	0.10219E-06	0.18099E-02
3	0.53680E-57	0.15939E-07	0.11561E-06	0.14570E-02
4	0.35147E-44	0.49276E-07	0.29225E-06	0.50364E-02
5	0.24492E-31	0.71209E-06	0.47744E-05	0.25792E-01
6	0.74890E-17	0.15671E-06	0.75150E-06	0.19180E-01
7	0.58398E-04	0.64064E-07	0.36882E-06	0.81461E-02
8	0.50551E-04	0.46516E-09	0.17594E-09	0.42487E-03
9	0.55327E-04	0.27377E-11	0.69289E-13	0.19182E-04
10	0.67214E-04	0.20658E-13	0.35567E-16	0.10600E-05
11	0.40852E-03	0.90172E-16	0.13103E-19	0.15646E-06

**** MOLE-Y-PROFILE ****

STAGE	WATER	METHA-01	ETHAN-01	PROPA-01	N-BUT-01
1	0.85645E-03	0.26010E-01	0.11154E-01	0.90170E-01	0.99960E-01
2	0.22599E-02	0.39627E-02	0.23620E-02	0.72980E-01	0.28000

3	0.19226E-03	0.34290E-02	0.15407E-02	0.22368E-01	0.12138
4	0.11698E-03	0.32394E-02	0.14306E-02	0.13504E-01	0.47752E-01
5	0.30606E-03	0.36043E-02	0.16272E-02	0.13884E-01	0.28709E-01
6	0.11860E-01	0.84696E-02	0.37480E-02	0.31966E-01	0.60516E-01
7	0.10649	0.45825E-02	0.21971E-02	0.20080E-01	0.41455E-01
8	0.28576	0.14292E-04	0.14917E-03	0.23341E-02	0.16831E-01
9	0.28034	0.39190E-07	0.89432E-05	0.24324E-03	0.59693E-02
10	0.12950	0.11434E-09	0.52632E-06	0.26449E-04	0.22332E-02
11	0.44075	0.24443E-12	0.21409E-07	0.17039E-05	0.60478E-03

**** MOLE-Y-PROFILE ****

STAGE	N-PEN-01	N-HEX-01	N-HEP-01	N-OCT-01	N-NON-01
1	0.23730E-01	0.37919E-07	0.19687E-12	0.65209E-14	0.25847E-18
2	0.51400	0.59689E-05	0.40246E-09	0.25632E-10	0.77590E-14
3	0.75134	0.30202E-04	0.93278E-08	0.86818E-09	0.93426E-12
4	0.83978	0.10609E-03	0.11662E-06	0.17524E-07	0.64115E-10
5	0.84368	0.42861E-03	0.19956E-05	0.50746E-06	0.67471E-08
6	0.62316	0.10318E-02	0.24902E-04	0.66243E-05	0.41056E-06
7	0.67151	0.54677E-02	0.70867E-03	0.33250E-03	0.79117E-04
8	0.67558	0.87441E-02	0.66523E-03	0.31467E-03	0.71734E-04
9	0.68763	0.23924E-01	0.91171E-03	0.37029E-03	0.78348E-04
10	0.76866	0.91561E-01	0.56253E-02	0.19115E-02	0.37878E-03
11	0.35409	0.14759	0.34151E-01	0.15186E-01	0.54334E-02

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MOLE-Y-PROFILE ****

STAGE	N-DEC-01	N-UND-01	N-DOD-01	N-TRI-01	N-TET-01
1	0.46457E-22	0.15181E-26	0.15725E-30	0.70661E-34	0.14355E-37
2	0.69973E-17	0.18623E-20	0.17457E-23	0.25379E-26	0.29585E-29
3	0.20761E-14	0.18930E-17	0.57703E-20	0.20641E-22	0.72625E-25
4	0.33113E-12	0.98410E-15	0.81924E-17	0.76388E-19	0.71350E-21
5	0.11089E-09	0.12549E-11	0.32667E-13	0.92951E-15	0.26471E-16
6	0.23789E-07	0.14010E-08	0.10608E-09	0.87716E-11	0.71477E-12
7	0.20115E-04	0.49356E-05	0.13452E-05	0.38411E-06	0.10919E-06
8	0.20758E-04	0.51101E-05	0.14386E-05	0.41759E-06	0.12226E-06
9	0.23046E-04	0.57383E-05	0.16375E-05	0.48631E-06	0.14513E-06
10	0.60334E-04	0.15298E-04	0.41795E-05	0.12244E-05	0.38343E-06
11	0.14263E-02	0.51417E-03	0.16837E-03	0.53675E-04	0.21536E-04

**** MOLE-Y-PROFILE ****

STAGE	N-PEN-02	N-HEX-02	N-HEP-02	N-OCT-02	N-NON-02
1	0.23869E-42	0.56374E-45	0.90450E-50	0.10408E-53	0.33205E-57
2	0.18267E-33	0.34721E-35	0.21853E-39	0.11318E-42	0.26826E-45
3	0.10886E-28	0.67832E-30	0.10373E-33	0.16525E-36	0.10051E-38
4	0.26957E-24	0.49007E-25	0.18028E-28	0.85855E-31	0.12044E-32
5	0.40834E-19	0.17725E-19	0.26329E-22	0.43962E-24	0.16935E-25
6	0.21283E-13	0.41036E-14	0.11727E-15	0.71646E-17	0.61649E-18
7	0.20065E-07	0.79108E-08	0.14108E-08	0.33887E-09	0.93941E-10
8	0.27198E-07	0.91381E-08	0.20065E-08	0.49614E-09	0.14077E-09
9	0.35605E-07	0.10909E-07	0.26820E-08	0.67748E-09	0.19625E-09
10	0.54605E-07	0.28220E-07	0.40591E-08	0.10288E-08	0.31431E-09
11	0.47616E-05	0.20410E-05	0.47229E-06	0.15894E-06	0.51542E-07

**** MOLE-Y-PROFILE ****

STAGE	N-EIC-01	N-HEN-01	N-DOC-01	N-TRI-02	N-TET-02
1	0.49749E-61	0.72984E-64	0.11364E-67	0.27395E-73	0.34730E-75
2	0.24678E-48	0.96099E-51	0.91367E-54	0.18225E-58	0.61511E-60
3	0.26550E-41	0.24483E-43	0.65035E-46	0.58088E-50	0.37775E-51
4	0.84967E-35	0.18174E-36	0.12532E-38	0.48896E-42	0.58039E-43
5	0.37835E-27	0.19550E-28	0.41501E-30	0.94629E-33	0.19899E-33
6	0.39846E-19	0.49293E-20	0.29289E-21	0.52586E-23	0.12225E-23
7	0.22192E-10	0.67979E-11	0.14503E-11	0.18932E-12	0.77771E-13

8	0.34052E-10	0.10416E-10	0.22717E-11	0.31992E-12	0.12801E-12
9	0.48055E-10	0.14482E-10	0.31721E-11	0.48535E-12	0.19311E-12
10	0.76503E-10	0.22334E-10	0.48396E-11	0.79299E-12	0.34394E-12
11	0.14859E-07	0.47134E-08	0.12802E-08	0.32269E-09	0.12082E-09

**** MOLE-Y-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
1	0.12078E-77	0.17485E-80	0.33829E-84	0.27671E-93	0.28901E-93
2	0.75192E-62	0.34276E-64	0.33783E-67	0.13510E-74	0.31665E-74
3	0.90051E-53	0.92740E-55	0.26313E-57	0.18689E-64	0.27945E-63
4	0.25397E-44	0.57406E-46	0.44607E-48	0.44618E-55	0.44011E-53
5	0.17095E-34	0.90970E-36	0.21833E-37	0.60153E-43	0.32266E-41
6	0.20260E-24	0.24319E-25	0.16729E-26	0.32562E-30	0.27473E-29
7	0.27167E-13	0.81631E-14	0.19351E-14	0.22895E-16	0.73645E-16
8	0.44909E-13	0.13661E-13	0.32952E-14	0.55577E-16	0.13472E-15
9	0.65714E-13	0.20348E-13	0.49566E-14	0.10909E-15	0.21164E-15
10	0.10184E-12	0.33882E-13	0.83761E-14	0.13866E-15	0.37268E-15

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MOLE-Y-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
11	0.34751E-10	0.12577E-10	0.36221E-11	0.24535E-12	0.26795E-12

**** MOLE-Y-PROFILE ****

STAGE	N-TRI-03	CARBO-01	HYDRO-01	CARBO-02
1	0.12468-100	0.43442E-04	0.39837E-02	0.74409
2	0.96816E-80	0.64535E-05	0.58899E-03	0.12384
3	0.56051E-68	0.57126E-05	0.52272E-03	0.99191E-01
4	0.47022E-57	0.54022E-05	0.49421E-03	0.93568E-01
5	0.30288E-44	0.60477E-05	0.55094E-03	0.10720
6	0.16577E-31	0.14521E-04	0.12906E-02	0.25792
7	0.61751E-17	0.77508E-05	0.69953E-03	0.14636
8	0.12181E-16	0.74749E-07	0.43034E-06	0.95047E-02
9	0.20022E-16	0.53085E-09	0.20079E-09	0.48485E-03
10	0.36564E-16	0.31666E-11	0.80143E-13	0.22163E-04
11	0.43193E-13	0.24708E-13	0.42568E-16	0.12379E-05

**** K-VALUES ****

STAGE	WATER	METHA-01	ETHAN-01	PROPA-01	N-BUT-01
1	5.2259	129.59	8.5777	0.89845	0.31095
2	56.957	300.91	34.330	5.4610	2.1351
3	62.308	348.96	44.497	7.8935	2.9741
4	55.872	314.54	40.060	6.6639	2.4901
5	3.9656	140.92	10.531	1.4160	0.58352
6	0.56650	243.95	11.574	4.9054	1.7673
7	0.26099	378.65	18.733	10.501	2.9601
8	0.39029	447.39	20.492	12.436	3.5335
9	1.4704	415.50	19.268	10.814	3.1782
10	0.28355	524.92	30.096	18.834	4.4049
11	1.3849	793.01	54.368	36.167	10.145

**** K-VALUES ****

STAGE	N-PEN-01	N-HEX-01	N-HEP-01	N-OCT-01	N-NON-01
1	0.57733E-01	0.87451E-02	0.54506E-03	0.44943E-03	0.76443E-04
2	0.52543	0.12607	0.18338E-01	0.13577E-01	0.33939E-02
3	0.70110	0.18561	0.36899E-01	0.22821E-01	0.58905E-02
4	0.55315	0.14187	0.28347E-01	0.15701E-01	0.40030E-02
5	0.10837	0.18308E-01	0.21981E-02	0.11877E-02	0.22249E-03
6	0.48009	0.98076E-01	0.18324E-01	0.97127E-02	0.24825E-02
7	1.2885	0.29880	0.62554E-01	0.34466E-01	0.10960E-01
8	1.4768	0.36456	0.80419E-01	0.48159E-01	0.14764E-01
9	1.0571	0.26920	0.58413E-01	0.34652E-01	0.10302E-01

10	2.7051	0.74940	0.14970	0.91517E-01	0.32804E-01
11	4.4914	1.6756	0.44426	0.22751	0.10442

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** K-VALUES ****

STAGE	N-DEC-01	N-UND-01	N-DOD-01	N-TRI-01	N-TET-01
1	0.18751E-04	0.28346E-05	0.34462E-06	0.13060E-06	0.23644E-07
2	0.11921E-02	0.29486E-03	0.68991E-04	0.27568E-04	0.74193E-05
3	0.21910E-02	0.57245E-03	0.16777E-03	0.59320E-04	0.18457E-04
4	0.14248E-02	0.35576E-03	0.10548E-03	0.33971E-04	0.10477E-04
5	0.61449E-04	0.10619E-04	0.21666E-05	0.58130E-06	0.13430E-06
6	0.72547E-03	0.17495E-03	0.46254E-04	0.14496E-04	0.40480E-05
7	0.26846E-02	0.76645E-03	0.23147E-03	0.77021E-04	0.24565E-04
8	0.39354E-02	0.11083E-02	0.35401E-03	0.11928E-03	0.39809E-04
9	0.32335E-02	0.91123E-03	0.29530E-03	0.10116E-03	0.34171E-04
10	0.70893E-02	0.22099E-02	0.72414E-03	0.25151E-03	0.92384E-04
11	0.28822E-01	0.12080E-01	0.45710E-02	0.16868E-02	0.79043E-03

**** K-VALUES ****

STAGE	N-PEN-02	N-HEX-02	N-HEP-02	N-OCT-02	N-NON-02
1	0.78892E-08	0.12103E-08	0.35543E-09	0.86338E-10	0.15457E-10
2	0.29324E-05	0.72202E-06	0.26901E-06	0.79258E-07	0.24764E-07
3	0.69045E-05	0.18905E-05	0.70771E-06	0.20946E-06	0.72403E-07
4	0.36792E-05	0.97124E-06	0.34499E-06	0.97971E-07	0.32437E-07
5	0.39135E-07	0.77922E-08	0.21316E-08	0.49826E-09	0.11350E-09
6	0.10610E-05	0.33280E-06	0.85429E-07	0.22738E-07	0.69218E-08
7	0.48468E-05	0.23176E-05	0.46784E-06	0.13295E-06	0.46660E-07
8	0.82721E-05	0.39651E-05	0.85715E-06	0.24866E-06	0.92018E-07
9	0.95517E-05	0.33495E-05	0.99612E-06	0.29623E-06	0.10978E-06
10	0.14424E-04	0.92970E-05	0.15545E-05	0.46920E-06	0.19223E-06
11	0.20777E-03	0.10100E-03	0.29601E-04	0.12063E-04	0.50708E-05

**** K-VALUES ****

STAGE	N-EIC-01	N-HEN-01	N-DOC-01	N-TRI-02	N-TET-02
1	0.30742E-11	0.11912E-11	0.23969E-12	0.33910E-13	0.13479E-13
2	0.73348E-08	0.30133E-08	0.91585E-09	0.17898E-09	0.85438E-10
3	0.22673E-07	0.93864E-08	0.30210E-08	0.58581E-09	0.29351E-09
4	0.97265E-08	0.39972E-08	0.12288E-08	0.22083E-09	0.11000E-09
5	0.25255E-10	0.98842E-11	0.22199E-11	0.28163E-12	0.12576E-12
6	0.19169E-08	0.77557E-09	0.21882E-09	0.34259E-10	0.17631E-10
7	0.14232E-07	0.58112E-08	0.18175E-08	0.31389E-09	0.18232E-09
8	0.29116E-07	0.11884E-07	0.38445E-08	0.69551E-09	0.40965E-09
9	0.34882E-07	0.13963E-07	0.44824E-08	0.91501E-09	0.51142E-09
10	0.62180E-07	0.24002E-07	0.78060E-08	0.17638E-08	0.10989E-08
11	0.19327E-05	0.82232E-06	0.33639E-06	0.11756E-06	0.61207E-07

**** K-VALUES ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
1	0.46277E-14	0.16040E-14	0.36595E-15	0.13021E-16	0.60665E-17
2	0.39573E-10	0.16343E-10	0.50391E-11	0.14768E-11	0.27670E-12
3	0.14599E-09	0.61775E-10	0.19861E-10	0.20105E-10	0.12879E-11
4	0.54329E-10	0.22548E-10	0.70113E-11	0.10339E-10	0.39816E-12
5	0.53336E-13	0.19380E-13	0.47951E-14	0.72040E-15	0.10983E-15
6	0.82685E-11	0.33224E-11	0.97254E-12	0.44122E-13	0.43558E-13
7	0.83486E-10	0.36534E-10	0.11542E-10	0.35142E-12	0.71171E-12
8	0.19248E-09	0.85170E-10	0.27667E-10	0.87998E-12	0.19023E-11
9	0.23251E-09	0.10413E-09	0.33907E-10	0.18861E-11	0.23681E-11
10	0.43478E-09	0.21243E-09	0.71766E-10	0.32141E-11	0.56423E-11

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** K-VALUES ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
11	0.23535E-07	0.12482E-07	0.48960E-08	0.99391E-09	0.63068E-09

**** K-VALUES ****

STAGE	N-TRI-03	CARBO-01	HYDRO-01	CARBO-02
1	0.16024E-18	431.43	11432.	27.037
2	0.25646E-13	783.85	13084.	95.156
3	0.14211E-12	880.21	13745.	118.45
4	0.38228E-13	840.80	13889.	104.56
5	0.40722E-17	295.22	7140.3	22.268
6	0.32627E-14	133.81	2436.6	16.317
7	0.73944E-13	123.44	1966.9	18.660
8	0.22182E-12	131.39	2002.6	21.225
9	0.28100E-12	186.20	2818.4	25.425
10	0.75383E-12	140.79	2029.1	21.407
11	0.13563E-09	262.00	3065.6	6.9464

**** MASS-X-PROFILE ****

STAGE	WATER	METHA-01	ETHAN-01	PROPA-01	N-BUT-01
1	0.69186E-03	0.34013E-04	0.38603E-03	0.47352E-01	0.27751
2	0.23668E-04	0.44000E-05	0.38231E-04	0.76408E-02	0.10347
3	0.30932E-05	0.34066E-05	0.22610E-04	0.16342E-02	0.32824E-01
4	0.54708E-04	0.22920E-05	0.41521E-04	0.10131E-02	0.14006E-01
5	0.44168E-02	0.21826E-04	0.91290E-04	0.26383E-02	0.34708E-01
6	0.36186E-01	0.58288E-05	0.13641E-03	0.35485E-02	0.26259E-01
7	0.82304E-01	0.31030E-05	0.60703E-04	0.13929E-02	0.13247E-01
8	0.80924E-01	0.87109E-08	0.37259E-05	0.14861E-03	0.48138E-02
9	0.38573E-01	0.22045E-10	0.19021E-06	0.14020E-04	0.15664E-02
10	0.12347	0.53558E-13	0.88218E-08	0.10315E-05	0.48931E-03
11	0.52960E-01	0.44965E-16	0.11023E-09	0.19288E-07	0.32804E-04

**** MASS-X-PROFILE ****

STAGE	N-PEN-01	N-HEX-01	N-HEP-01	N-OCT-01	N-NON-01
1	0.66305	0.92511E-05	0.72593E-09	0.52707E-10	0.17915E-13
2	0.88765	0.42788E-04	0.15368E-07	0.16306E-08	0.19702E-11
3	0.96447	0.14603E-03	0.18666E-06	0.31975E-07	0.13136E-09
4	0.98119	0.59769E-03	0.32358E-05	0.93802E-06	0.14003E-07
5	0.93991	0.18819E-02	0.52814E-04	0.16016E-04	0.11145E-05
6	0.90949	0.89002E-02	0.13413E-02	0.71743E-03	0.19167E-03
7	0.67239	0.27646E-01	0.18666E-01	0.18074E-01	0.15756E-01
8	0.69842	0.43688E-01	0.16663E-01	0.15830E-01	0.13688E-01
9	0.67710	0.10938	0.21589E-01	0.17292E-01	0.13620E-01
10	0.36401	0.19446	0.67889E-01	0.44637E-01	0.28137E-01
11	0.53360E-01	0.73145E-01	0.74467E-01	0.73726E-01	0.65528E-01

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MASS-X-PROFILE ****

STAGE	N-DEC-01	N-UND-01	N-DOD-01	N-TRI-01	N-TET-01
1	0.17923E-16	0.52404E-20	0.53531E-23	0.84232E-26	0.10566E-28
2	0.48570E-14	0.48653E-17	0.16161E-19	0.62573E-22	0.23691E-24
3	0.75260E-12	0.24572E-14	0.22291E-16	0.22496E-18	0.22611E-20
4	0.25531E-09	0.31742E-11	0.90042E-13	0.27731E-14	0.84981E-16
5	0.71642E-07	0.46352E-08	0.38246E-09	0.34228E-10	0.30014E-11
6	0.54061E-04	0.14573E-04	0.43281E-05	0.13376E-05	0.40920E-06
7	0.16629E-01	0.15843E-01	0.15060E-01	0.14118E-01	0.13219E-01
8	0.14424E-01	0.13736E-01	0.13054E-01	0.12237E-01	0.11458E-01
9	0.13938E-01	0.13233E-01	0.12566E-01	0.11776E-01	0.11025E-01
10	0.22533E-01	0.19959E-01	0.18328E-01	0.16952E-01	0.15805E-01
11	0.69542E-01	0.66371E-01	0.63118E-01	0.59178E-01	0.55412E-01

**** MASS-X-PROFILE ****

STAGE	N-PEN-02	N-HEX-02	N-HEP-02	N-OCT-02	N-NON-02
1	0.69852E-33	0.14154E-34	0.94602E-39	0.51853E-42	0.12968E-44
2	0.38021E-28	0.25256E-29	0.41014E-33	0.69150E-36	0.44377E-38
3	0.91470E-24	0.17727E-24	0.69251E-28	0.34903E-30	0.51659E-32
4	0.14036E-18	0.64948E-19	0.10245E-21	0.18105E-23	0.73588E-25
5	0.95686E-13	0.19668E-13	0.59688E-15	0.38593E-16	0.35038E-17
6	0.80509E-07	0.33837E-07	0.64083E-08	0.16290E-08	0.47649E-09
7	0.11959E-01	0.11376E-01	0.95773E-02	0.84872E-02	0.69587E-02
8	0.10366E-01	0.98607E-02	0.83014E-02	0.73565E-02	0.60316E-02
9	0.99738E-02	0.94877E-02	0.79873E-02	0.70782E-02	0.58034E-02
10	0.14260E-01	0.13559E-01	0.11411E-01	0.10111E-01	0.82899E-02
11	0.50132E-01	0.47690E-01	0.40148E-01	0.35579E-01	0.29171E-01

**** MASS-X-PROFILE ****

STAGE	N-EIC-01	N-HEN-01	N-DOC-01	N-TRI-02	N-TET-02
1	0.12553E-47	0.51307E-50	0.51088E-53	0.10651E-57	0.37501E-59
2	0.12335E-40	0.11939E-42	0.33214E-45	0.31006E-49	0.21035E-50
3	0.38349E-34	0.86101E-36	0.62176E-38	0.25356E-41	0.31398E-42
4	0.17299E-26	0.93825E-28	0.20859E-29	0.49710E-32	0.10905E-32
5	0.23830E-18	0.30943E-19	0.19255E-20	0.36132E-22	0.87629E-23
6	0.11844E-09	0.38082E-10	0.85092E-11	0.11609E-11	0.49750E-12
7	0.55943E-02	0.43936E-02	0.30921E-02	0.23955E-02	0.17852E-02
8	0.48490E-02	0.38083E-02	0.26801E-02	0.20764E-02	0.15473E-02
9	0.46655E-02	0.36642E-02	0.25788E-02	0.19978E-02	0.14888E-02
10	0.66644E-02	0.52340E-02	0.36835E-02	0.28537E-02	0.21266E-02
11	0.23451E-01	0.18418E-01	0.12962E-01	0.10042E-01	0.74835E-02

**** MASS-X-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
1	0.47740E-61	0.22628E-63	0.23155E-66	0.96012E-74	0.23302E-73
2	0.52221E-52	0.55920E-54	0.16472E-56	0.12131E-63	0.18783E-62
3	0.14308E-43	0.33628E-45	0.27129E-47	0.28136E-54	0.28739E-52
4	0.97563E-34	0.53983E-35	0.13451E-36	0.38426E-42	0.21344E-40
5	0.15124E-23	0.18876E-24	0.13481E-25	0.27207E-29	0.23771E-28
6	0.18098E-12	0.56545E-13	0.13917E-13	0.17072E-15	0.56866E-15
7	0.13952E-02	0.99182E-03	0.76517E-03	0.28458E-03	0.48731E-03
8	0.12093E-02	0.85968E-03	0.66323E-03	0.24666E-03	0.42239E-03
9	0.11636E-02	0.82716E-03	0.63814E-03	0.23733E-03	0.40641E-03
10	0.16621E-02	0.11815E-02	0.91153E-03	0.33901E-03	0.58052E-03

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MASS-X-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
11	0.58488E-02	0.41577E-02	0.32076E-02	0.11929E-02	0.20428E-02

**** MASS-X-PROFILE ****

STAGE	N-TRI-03	CARBO-01	HYDRO-01	CARBO-02
1	0.73693E-79	0.15970E-07	0.34205E-08	0.10965E-01
2	0.38968E-67	0.61327E-08	0.29429E-08	0.11379E-02
3	0.31759E-56	0.62471E-08	0.32611E-08	0.89722E-03
4	0.20723E-43	0.19247E-07	0.82156E-08	0.30909E-02
5	0.14835E-30	0.28574E-06	0.13788E-06	0.16261E-01
6	0.49319E-16	0.68367E-07	0.23595E-07	0.13147E-01
7	0.38990E-03	0.28335E-07	0.11740E-07	0.56610E-02
8	0.33795E-03	0.20601E-09	0.56079E-11	0.29565E-03
9	0.32517E-03	0.10659E-11	0.19415E-14	0.11735E-04
10	0.46448E-03	0.94569E-14	0.11718E-17	0.76244E-06
11	0.16345E-02	0.23900E-16	0.24993E-21	0.65157E-07

**** MASS-Y-PROFILE ****

STAGE	WATER	METHA-01	ETHAN-01	PROPA-01	N-BUT-01
1	0.34270E-03	0.92680E-02	0.74496E-02	0.88315E-01	0.12904
2	0.65451E-03	0.10220E-02	0.11418E-02	0.51735E-01	0.26162
3	0.51910E-04	0.82444E-03	0.69430E-03	0.14782E-01	0.10573
4	0.30906E-04	0.76215E-03	0.63086E-03	0.87331E-02	0.40704E-01
5	0.81058E-04	0.85007E-03	0.71933E-03	0.90009E-02	0.24531E-01
6	0.34576E-02	0.21988E-02	0.18238E-02	0.22810E-01	0.56919E-01
7	0.31533E-01	0.12083E-02	0.10859E-02	0.14554E-01	0.39604E-01
8	0.91497E-01	0.40751E-05	0.79720E-04	0.18293E-02	0.17387E-01
9	0.88214E-01	0.10981E-07	0.46970E-05	0.18735E-03	0.60600E-02
10	0.35000E-01	0.27520E-10	0.23743E-06	0.17497E-04	0.19473E-02
11	0.15146	0.74802E-13	0.12280E-07	0.14333E-05	0.67054E-03

**** MASS-Y-PROFILE ****

STAGE	N-PEN-01	N-HEX-01	N-HEP-01	N-OCT-01	N-NON-01
1	0.38028E-01	0.72579E-07	0.43816E-12	0.16545E-13	0.73632E-18
2	0.59618	0.82691E-05	0.64831E-09	0.47070E-10	0.15998E-13
3	0.81244	0.39007E-04	0.14008E-07	0.14863E-08	0.17958E-11
4	0.88860	0.13407E-03	0.17138E-06	0.29357E-07	0.12060E-09
5	0.89489	0.54301E-03	0.29397E-05	0.85220E-06	0.12722E-07
6	0.72757	0.14388E-02	0.40379E-04	0.12245E-04	0.85212E-06
7	0.79635	0.77447E-02	0.11672E-02	0.62429E-03	0.16679E-03
8	0.86632	0.13393E-01	0.11847E-02	0.63884E-03	0.16352E-03
9	0.86656	0.36010E-01	0.15957E-02	0.73880E-03	0.17552E-03
10	0.83200	0.11837	0.84564E-02	0.32758E-02	0.72882E-03
11	0.48734	0.24261	0.65277E-01	0.33089E-01	0.13293E-01

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MASS-Y-PROFILE ****

STAGE	N-DEC-01	N-UND-01	N-DOD-01	N-TRI-01	N-TET-01
1	0.14682E-21	0.52706E-26	0.59492E-30	0.28935E-33	0.63253E-37
2	0.16005E-16	0.46798E-20	0.47804E-23	0.75220E-26	0.94357E-29
3	0.44270E-14	0.44346E-17	0.14731E-19	0.57033E-22	0.21594E-24
4	0.69096E-12	0.22560E-14	0.20466E-16	0.20654E-18	0.20760E-20
5	0.23195E-09	0.28837E-11	0.81803E-13	0.25193E-14	0.77206E-16
6	0.54774E-07	0.35439E-08	0.29241E-09	0.26169E-10	0.22947E-11
7	0.47043E-04	0.12681E-04	0.37662E-05	0.11640E-05	0.35607E-06
8	0.52494E-04	0.14197E-04	0.43552E-05	0.13683E-05	0.43111E-06
9	0.57274E-04	0.15667E-04	0.48718E-05	0.15660E-05	0.50290E-06
10	0.12879E-03	0.35873E-04	0.10681E-04	0.33864E-05	0.11412E-05
11	0.38711E-02	0.15331E-02	0.54708E-03	0.18876E-03	0.81502E-04

**** MASS-Y-PROFILE ****

STAGE	N-PEN-02	N-HEX-02	N-HEP-02	N-OCT-02	N-NON-02
1	0.11262E-41	0.28354E-44	0.48310E-49	0.58833E-53	0.19804E-56
2	0.62378E-33	0.12639E-34	0.84480E-39	0.46305E-42	0.11580E-44
3	0.34655E-28	0.23020E-29	0.37383E-33	0.63028E-36	0.40449E-38
4	0.83979E-24	0.16275E-24	0.63580E-28	0.32044E-30	0.47429E-32
5	0.12752E-18	0.59006E-19	0.93078E-22	0.16448E-23	0.66855E-25
6	0.73157E-13	0.15037E-13	0.45635E-15	0.29506E-16	0.26789E-17
7	0.70057E-07	0.29444E-07	0.55763E-08	0.14175E-08	0.41462E-09
8	0.10268E-06	0.36777E-07	0.85758E-08	0.22442E-08	0.67183E-09
9	0.13210E-06	0.43146E-07	0.11265E-07	0.30115E-08	0.92043E-09
10	0.17401E-06	0.95868E-07	0.14644E-07	0.39280E-08	0.12662E-08
11	0.19294E-04	0.88163E-05	0.21665E-05	0.77161E-06	0.26401E-06

**** MASS-Y-PROFILE ****

STAGE	N-EIC-01	N-HEN-01	N-DOC-01	N-TRI-02	N-TET-02
1	0.31222E-60	0.48077E-63	0.78399E-67	0.19753E-72	0.26124E-74
2	0.11210E-47	0.45818E-50	0.45622E-53	0.95114E-58	0.33488E-59
3	0.11243E-40	0.10882E-42	0.30274E-45	0.28261E-49	0.19173E-50
4	0.35209E-34	0.79050E-36	0.57084E-38	0.23279E-41	0.28826E-42

5	0.15716E-26	0.85240E-28	0.18951E-29	0.45162E-32	0.99070E-33
6	0.18219E-18	0.23657E-19	0.14721E-20	0.27625E-22	0.66998E-23
7	0.10306E-09	0.33138E-10	0.74045E-11	0.10102E-11	0.43291E-12
8	0.17100E-09	0.54904E-10	0.12541E-10	0.18458E-11	0.77047E-12
9	0.23716E-09	0.75021E-10	0.17209E-10	0.27520E-11	0.11423E-11
10	0.32429E-09	0.99372E-10	0.22551E-10	0.38620E-11	0.17474E-11
11	0.80086E-07	0.26665E-07	0.75853E-08	0.19982E-08	0.78053E-09

**** MASS-Y-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
1	0.94612E-77	0.14241E-79	0.28608E-83	0.24262E-92	0.26241E-92
2	0.42632E-61	0.20207E-63	0.20678E-66	0.85739E-74	0.20809E-73
3	0.47598E-52	0.50969E-54	0.15014E-56	0.11057E-63	0.17120E-62
4	0.13136E-43	0.30874E-45	0.24908E-47	0.25832E-54	0.26386E-52
5	0.88637E-34	0.49044E-35	0.12221E-36	0.34910E-42	0.19391E-40
6	0.11563E-23	0.14432E-24	0.10307E-25	0.20801E-29	0.18174E-28
7	0.15749E-12	0.49203E-13	0.12110E-13	0.14855E-15	0.49483E-15
8	0.28150E-12	0.89037E-13	0.22298E-13	0.38994E-15	0.97878E-15
9	0.40481E-12	0.13034E-12	0.32962E-13	0.75219E-15	0.15111E-14
10	0.53885E-12	0.18640E-12	0.47844E-13	0.82121E-15	0.22856E-14

U-O-S BLOCK SECTION

BLOCK: DIST1 MODEL: RADFRAC (CONTINUED)

**** MASS-Y-PROFILE ****

STAGE	N-PEN-03	N-HEX-03	N-HEP-03	N-OCT-03	N-NON-03
11	0.23379E-09	0.87982E-10	0.26306E-10	0.18475E-11	0.20895E-11

**** MASS-Y-PROFILE ****

STAGE	N-TRI-03	CARBO-01	HYDRO-01	CARBO-02
1	0.11709E-99	0.27027E-04	0.17837E-03	0.72735
2	0.65808E-79	0.29060E-05	0.19087E-04	0.87613E-01
3	0.35519E-67	0.23981E-05	0.15792E-04	0.65424E-01
4	0.29158E-56	0.22192E-05	0.14611E-04	0.60391E-01
5	0.18827E-43	0.24904E-05	0.16328E-04	0.69358E-01
6	0.11342E-30	0.65818E-05	0.42101E-04	0.18368
7	0.42915E-16	0.35684E-05	0.23178E-04	0.10587
8	0.91541E-16	0.37212E-07	0.15418E-07	0.74345E-02
9	0.14787E-15	0.25971E-09	0.70697E-11	0.37270E-03
10	0.23193E-15	0.13307E-11	0.24237E-14	0.14633E-04
11	0.34837E-12	0.13202E-13	0.16369E-17	0.10393E-05

BLOCK: FLASH1 MODEL: FLASH2

INLET STREAM: FTPROD
OUTLET VAPOR STREAM: FLASHGAS
OUTLET LIQUID STREAM: FLASLIQ2
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	5054.39	5054.39	0.00000
MASS(LB/HR)	54202.7	54202.6	0.189313E-05
ENTHALPY(BTU/HR)	-0.191503E+09	-0.195802E+09	0.219576E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	23527.9	LB/HR
PRODUCT STREAMS CO2E	23527.9	LB/HR
NET STREAMS CO2E PRODUCTION	0.217267E-01	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.217267E-01	LB/HR

BLOCK: FLASH1 MODEL: FLASH2 (CONTINUED)

*** INPUT DATA ***

THREE PHASE TP FLASH		
SPECIFIED TEMPERATURE	C	50.4573
PRESSURE DROP	PSI	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	50.457
OUTLET PRESSURE	PSIA	362.59
HEAT DUTY	BTU/HR	-0.42993E+07
VAPOR FRACTION		0.79330
1ST LIQUID/TOTAL LIQUID		0.42871E-01

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
WATER	0.194	0.106E-01	0.961	0.490E-02	0.462	0.510E-02
METHA-01	0.301E-02	0.742E-03	0.320E-04	0.378E-02	5.09	118.
ETHAN-01	0.262E-02	0.984E-03	0.790E-05	0.328E-02	3.34	415.
PROPA-01	0.227E-02	0.361E-02	0.455E-04	0.281E-02	0.778	61.8
N-BUT-01	0.198E-02	0.958E-02	0.487E-04	0.237E-02	0.248	48.8
N-PEN-01	0.172E-02	0.239E-01	0.114E-05	0.190E-02	0.795E-01	0.168E+04
N-HEX-01	0.150E-02	0.501E-01	0.333E-05	0.133E-02	0.265E-01	398.
N-HEP-01	0.131E-02	0.936E-01	0.870E-05	0.598E-03	0.639E-02	68.8
N-OCT-01	0.113E-02	0.116	0.148E-05	0.135E-03	0.117E-02	91.3
N-NON-01	0.987E-03	0.974E-01	0.205E-03	0.106E-03	0.109E-02	0.517
N-DEC-01	0.859E-03	0.943E-01	0.126E-05	0.287E-04	0.304E-03	22.7
N-UND-01	0.746E-03	0.829E-01	0.518E-05	0.128E-04	0.154E-03	2.47
N-DOD-01	0.651E-03	0.730E-01	0.465E-05	0.404E-05	0.554E-04	0.870
N-TRI-01	0.564E-03	0.634E-01	0.424E-05	0.132E-05	0.208E-04	0.311
N-TET-01	0.491E-03	0.552E-01	0.370E-05	0.458E-06	0.829E-05	0.124
N-PEN-02	0.427E-03	0.191E-01	0.130E-02	0.664E-07	0.347E-05	0.509E-04
N-HEX-02	0.370E-03	0.417E-01	0.276E-05	0.402E-07	0.965E-06	0.146E-01
N-HEP-02	0.319E-03	0.907E-02	0.120E-02	0.397E-08	0.437E-06	0.330E-05
N-OCT-02	0.283E-03	0.643E-02	0.114E-02	0.113E-08	0.176E-06	0.991E-06
N-NON-02	0.243E-03	0.441E-02	0.103E-02	0.285E-09	0.646E-07	0.276E-06
N-EIC-01	0.214E-03	0.336E-02	0.929E-03	0.773E-10	0.230E-07	0.831E-07
N-HEN-01	0.188E-03	0.267E-02	0.831E-03	0.260E-10	0.974E-08	0.313E-07
N-DOC-01	0.156E-03	0.198E-02	0.701E-03	0.733E-11	0.369E-08	0.104E-07
N-TRI-02	0.140E-03	0.167E-02	0.635E-03	0.210E-11	0.126E-08	0.331E-08
N-TET-02	0.123E-03	0.140E-02	0.558E-03	0.849E-12	0.609E-09	0.152E-08
N-PEN-03	0.107E-03	0.127E-02	0.483E-03	0.273E-12	0.215E-09	0.566E-09
N-HEX-03	0.930E-04	0.938E-03	0.428E-03	0.105E-12	0.112E-09	0.246E-09
N-HEP-03	0.811E-04	0.790E-03	0.375E-03	0.323E-13	0.409E-10	0.863E-10
N-OCT-03	0.692E-04	0.704E-03	0.319E-03	0.577E-14	0.819E-11	0.181E-10
N-NON-03	0.613E-04	0.575E-03	0.284E-03	0.244E-14	0.424E-11	0.859E-11
N-TRI-03	0.534E-04	0.458E-03	0.249E-03	0.346E-15	0.754E-12	0.139E-11
CARBO-01	0.235E-03	0.616E-05	0.823E-05	0.295E-03	47.9	35.8
HYDRO-01	0.704	0.145E-02	0.193E-02	0.888	612.	459.
CARBO-02	0.783E-01	0.127	0.257E-01	0.909E-01	0.717	3.53

BLOCK: FLASH3 MODEL: FLASH2

INLET STREAM:	COLDFLAS
OUTLET VAPOR STREAM:	FLASHG2
OUTLET LIQUID STREAM:	FLASHLQ3
PROPERTY OPTION SET:	NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	4009.66	4009.66	0.00000
MASS(LB/HR)	26686.6	26686.6	0.917421E-11
ENTHALPY(BTU/HR)	-0.719663E+08	-0.723602E+08	0.544386E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	22118.6	LB/HR
PRODUCT STREAMS CO2E	22118.6	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

THREE PHASE TP FLASH		
SPECIFIED TEMPERATURE	C	-59.6022
PRESSURE DROP	PSI	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	-59.602
OUTLET PRESSURE	PSIA	363.00
HEAT DUTY	BTU/HR	-0.39392E+06
VAPOR FRACTION		0.97564
1ST LIQUID/TOTAL LIQUID		1.0000

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
WATER	0.490E-02	0.201	0.201	0.421E-06	0.209E-05	0.209E-05
METHA-01	0.378E-02	0.218E-01	0.218E-01	0.333E-02	0.153	0.153
ETHAN-01	0.328E-02	0.911E-02	0.911E-02	0.314E-02	0.344	0.344
PROPA-01	0.281E-02	0.760E-01	0.760E-01	0.983E-03	0.129E-01	0.129E-01
N-BUT-01	0.237E-02	0.820E-01	0.820E-01	0.386E-03	0.470E-02	0.470E-02
N-PEN-01	0.190E-02	0.766E-01	0.766E-01	0.384E-04	0.501E-03	0.501E-03
N-HEX-01	0.133E-02	0.543E-01	0.543E-01	0.536E-05	0.987E-04	0.987E-04
N-HEP-01	0.598E-03	0.246E-01	0.246E-01	0.131E-06	0.533E-05	0.533E-05

U-O-S BLOCK SECTION

BLOCK: FLASH3 MODEL: FLASH2 (CONTINUED)

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
N-OCT-01	0.135E-03	0.556E-02	0.556E-02	0.166E-07	0.299E-05	0.299E-05
N-NON-01	0.106E-03	0.434E-02	0.434E-02	0.484E-09	0.111E-06	0.111E-06
N-DEC-01	0.287E-04	0.118E-02	0.118E-02	0.652E-10	0.554E-07	0.554E-07
N-UND-01	0.128E-04	0.525E-03	0.525E-03	0.844E-12	0.161E-08	0.161E-08
N-DOD-01	0.404E-05	0.166E-03	0.166E-03	0.344E-13	0.208E-09	0.208E-09
N-TRI-01	0.132E-05	0.542E-04	0.542E-04	0.265E-14	0.488E-10	0.488E-10
N-TET-01	0.458E-06	0.188E-04	0.188E-04	0.143E-15	0.761E-11	0.761E-11
N-PEN-02	0.664E-07	0.273E-05	0.273E-05	0.291E-17	0.107E-11	0.107E-11
N-HEX-02	0.402E-07	0.165E-05	0.165E-05	0.346E-18	0.209E-12	0.209E-12
N-HEP-02	0.397E-08	0.163E-06	0.163E-06	0.398E-20	0.245E-13	0.245E-13
N-OCT-02	0.113E-08	0.465E-07	0.465E-07	0.210E-21	0.451E-14	0.451E-14
N-NON-02	0.285E-09	0.117E-07	0.117E-07	0.633E-23	0.541E-15	0.541E-15
N-EIC-01	0.773E-10	0.317E-08	0.317E-08	0.235E-24	0.739E-16	0.739E-16
N-HEN-01	0.260E-10	0.107E-08	0.107E-08	0.279E-25	0.262E-16	0.262E-16
N-DOC-01	0.733E-11	0.301E-09	0.301E-09	0.914E-27	0.304E-17	0.304E-17
N-TRI-02	0.210E-11	0.862E-10	0.862E-10	0.279E-28	0.324E-18	0.324E-18
N-TET-02	0.849E-12	0.349E-10	0.349E-10	0.460E-29	0.132E-18	0.132E-18
N-PEN-03	0.273E-12	0.112E-10	0.112E-10	0.362E-30	0.322E-19	0.322E-19

N-HEX-03	0.105E-12	0.432E-11	0.432E-11	0.425E-31	0.982E-20	0.982E-20
N-HEP-03	0.323E-13	0.133E-11	0.133E-11	0.226E-32	0.170E-20	0.170E-20
N-OCT-03	0.577E-14	0.237E-12	0.237E-12	0.475E-35	0.201E-22	0.201E-22
N-NON-03	0.244E-14	0.100E-12	0.100E-12	0.921E-36	0.919E-23	0.919E-23
CARBO-01	0.295E-03	0.340E-04	0.340E-04	0.301E-03	8.87	8.87
HYDRO-01	0.888	0.263E-02	0.263E-02	0.910	346.	346.
CARBO-02	0.909E-01	0.440	0.440	0.822E-01	0.187	0.187

BLOCK: FLASH4 MODEL: FLASH2

INLET STREAM: FUELFLAS
OUTLET VAPOR STREAM: GASOLINE
OUTLET LIQUID STREAM: DIESEL
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	84.0039	84.0039	0.169169E-15
MASS(LB/HR)	8877.67	8877.67	0.189323E-12
ENTHALPY(BTU/HR)	-0.844489E+07	-0.844226E+07	-0.312163E-03

U-O-S BLOCK SECTION

BLOCK: FLASH4 MODEL: FLASH2 (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.578440E-03	LB/HR
PRODUCT STREAMS CO2E	0.578440E-03	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH		
SPECIFIED TEMPERATURE	C	170.000
SPECIFIED PRESSURE	PSIA	14.5038
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	170.00
OUTLET PRESSURE	PSIA	14.504
HEAT DUTY	BTU/HR	2636.2
VAPOR FRACTION		0.76769

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	0.31068	0.17469E-02	0.40416	231.35
ETHAN-01	0.38740E-09	0.15388E-11	0.50416E-09	327.64
PROPA-01	0.46225E-07	0.56771E-09	0.60040E-07	105.76
N-BUT-01	0.59645E-04	0.15944E-05	0.77212E-04	48.428
N-PEN-01	0.78158E-01	0.48566E-02	0.10034	20.660
N-HEX-01	0.89699E-01	0.12560E-01	0.11304	9.0003
N-HEP-01	0.78538E-01	0.20566E-01	0.96080E-01	4.6717
N-OCT-01	0.68208E-01	0.28004E-01	0.80374E-01	2.8701
N-NON-01	0.53994E-01	0.38914E-01	0.58557E-01	1.5048
N-DEC-01	0.51652E-01	0.60060E-01	0.49108E-01	0.81764
N-UND-01	0.44873E-01	0.71983E-01	0.36670E-01	0.50942
N-DOD-01	0.39160E-01	0.86601E-01	0.24804E-01	0.28641
N-TRI-01	0.33922E-01	0.94833E-01	0.15490E-01	0.16334
N-TET-01	0.29517E-01	0.93317E-01	0.10211E-01	0.10943

N-PEN-02	0.24942E-01	0.88329E-01	0.57605E-02	0.65216E-01
N-HEX-02	0.22257E-01	0.86915E-01	0.26909E-02	0.30960E-01
N-HEP-02	0.17644E-01	0.71547E-01	0.13331E-02	0.18633E-01
N-OCT-02	0.14774E-01	0.61215E-01	0.72085E-03	0.11776E-01
N-NON-02	0.11480E-01	0.48347E-01	0.32463E-03	0.67146E-02
N-EIC-01	0.87713E-02	0.37275E-01	0.14597E-03	0.39160E-02
N-HEN-01	0.65630E-02	0.28037E-01	0.65040E-04	0.23198E-02
N-DOC-01	0.44103E-02	0.18895E-01	0.27255E-04	0.14425E-02
N-TRI-02	0.32691E-02	0.14034E-01	0.11623E-04	0.82822E-03
N-TET-02	0.23353E-02	0.10036E-01	0.50088E-05	0.49908E-03
N-PEN-03	0.17526E-02	0.75368E-02	0.22428E-05	0.29758E-03
N-HEX-03	0.11982E-02	0.51547E-02	0.94304E-06	0.18295E-03
N-HEP-03	0.89033E-03	0.38313E-02	0.39192E-06	0.10230E-03

U-O-S BLOCK SECTION

BLOCK: FLASH4 MODEL: FLASH2 (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
N-OCT-03	0.31936E-03	0.13744E-02	0.89552E-07	0.65156E-04
N-NON-03	0.52811E-03	0.22730E-02	0.94667E-07	0.41648E-04
N-TRI-03	0.40852E-03	0.17584E-02	0.38726E-07	0.22023E-04
CARBO-02	0.15646E-06	0.14656E-07	0.19937E-06	13.603

BLOCK: FLASHLUB MODEL: FLASH2

INLET STREAM: FEEDLUB
OUTLET VAPOR STREAM: MIDALK
OUTLET LIQUID STREAM: LUBE
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.794034E-01	0.794034E-01	0.00000
MASS(LB/HR)	18.5699	18.5699	-0.382631E-15
ENTHALPY(BTU/HR)	-9115.56	-9115.54	-0.187150E-05

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.551765E-01	LB/HR
PRODUCT STREAMS CO2E	0.551765E-01	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH		
SPECIFIED TEMPERATURE	C	350.000
SPECIFIED PRESSURE	PSIA	362.594
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	350.00
OUTLET PRESSURE	PSIA	362.59
HEAT DUTY	BTU/HR	0.17060E-01
VAPOR FRACTION		0.95987E-01

U-O-S BLOCK SECTION

BLOCK: FLASHLUB MODEL: FLASH2 (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	0.56164E-01	0.40807E-02	0.54668	133.97
METHA-01	0.43664E-04	0.42742E-05	0.41464E-03	97.009
ETHAN-01	0.94268E-03	0.18263E-03	0.81009E-02	44.356
PROPA-01	0.16974E-02	0.56146E-03	0.12395E-01	22.077
N-BUT-01	0.53048E-02	0.25263E-02	0.31472E-01	12.458
N-PEN-01	0.69798E-02	0.45489E-02	0.29875E-01	6.5676
N-HEX-01	0.19441E-01	0.14639E-01	0.64666E-01	4.4175
N-HEP-01	0.12198E-01	0.10593E-01	0.27313E-01	2.5783
N-OCT-01	0.19221E-03	0.20947E-03	0.29702E-04	0.14180
N-NON-01	0.40663E-01	0.39436E-01	0.52222E-01	1.3242
N-DEC-01	0.67749E-02	0.70063E-02	0.45958E-02	0.65596
N-UND-01	0.58391E-02	0.60581E-02	0.37762E-02	0.62333
N-DOD-01	0.51061E-02	0.53947E-02	0.23874E-02	0.44254
N-TRI-01	0.48191E-02	0.51574E-02	0.16337E-02	0.31678
N-TET-01	0.43869E-02	0.47094E-02	0.13502E-02	0.28670
N-PEN-02	0.10554	0.11451	0.21049E-01	0.18381
N-HEX-02	0.33798E-02	0.36848E-02	0.50755E-03	0.13774
N-HEP-02	0.13016	0.14243	0.14604E-01	0.10253
N-OCT-02	0.13578	0.14894	0.11792E-01	0.79170E-01
N-NON-02	0.12592	0.13839	0.84234E-02	0.60865E-01
N-EIC-01	0.10166	0.11191	0.51179E-02	0.45730E-01
N-HEN-01	0.76315E-01	0.84102E-01	0.29797E-02	0.35430E-01
N-DOC-01	0.48976E-01	0.54017E-01	0.14987E-02	0.27745E-01
N-TRI-02	0.32924E-01	0.36336E-01	0.78174E-03	0.21514E-01
N-TET-02	0.20639E-01	0.22790E-01	0.38100E-03	0.16718E-01
N-PEN-03	0.12770E-01	0.14106E-01	0.18585E-03	0.13175E-01
N-HEX-03	0.81661E-02	0.90233E-02	0.93336E-04	0.10344E-01
N-HEP-03	0.52506E-02	0.58031E-02	0.46519E-04	0.80162E-02
N-OCT-03	0.34301E-03	0.37918E-03	0.23604E-05	0.62250E-02
N-NON-03	0.23540E-02	0.26024E-02	0.13737E-04	0.52786E-02
N-TRI-03	0.21800E-02	0.24107E-02	0.68596E-05	0.28455E-02
CARBO-01	0.71534E-05	0.49490E-06	0.69864E-04	141.17
HYDRO-01	0.16847E-02	0.30544E-04	0.17264E-01	565.22
CARBO-02	0.15391E-01	0.34065E-02	0.12827	37.653

BLOCK: FUELHEAT MODEL: HEATER

INLET STREAM: FLASHFE
OUTLET STREAM: FUELFLAS
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	84.0039	84.0039	0.00000
MASS(LB/HR)	8877.67	8877.67	-0.204895E-15
ENTHALPY(BTU/HR)	-0.104179E+08	-0.844489E+07	-0.189383

U-O-S BLOCK SECTION

BLOCK: FUELHEAT MODEL: HEATER (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.578440E-03	LB/HR
PRODUCT STREAMS CO2E	0.578440E-03	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	C	170.000
SPECIFIED PRESSURE	PSIA	14.7000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	170.00
OUTLET PRESSURE	PSIA	14.700
HEAT DUTY	BTU/HR	0.19730E+07
OUTLET VAPOR FRACTION		0.76601

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	0.31068	0.17778E-02	0.40503	227.83
ETHAN-01	0.38740E-09	0.15626E-11	0.50526E-09	323.34
PROPA-01	0.46225E-07	0.57666E-09	0.60168E-07	104.34
N-BUT-01	0.59645E-04	0.16187E-05	0.77371E-04	47.797
N-PEN-01	0.78158E-01	0.49305E-02	0.10053	20.389
N-HEX-01	0.89699E-01	0.12745E-01	0.11321	8.8821
N-HEP-01	0.78538E-01	0.20880E-01	0.96150E-01	4.6048
N-OCT-01	0.68208E-01	0.28384E-01	0.80373E-01	2.8316
N-NON-01	0.53994E-01	0.39356E-01	0.58466E-01	1.4856
N-DEC-01	0.51652E-01	0.60627E-01	0.48910E-01	0.80674
N-UND-01	0.44873E-01	0.72481E-01	0.36440E-01	0.50275
N-DOD-01	0.39160E-01	0.86925E-01	0.24569E-01	0.28264
N-TRI-01	0.33922E-01	0.94900E-01	0.15295E-01	0.16117
N-TET-01	0.29517E-01	0.93209E-01	0.10061E-01	0.10794
N-PEN-02	0.24942E-01	0.88045E-01	0.56656E-02	0.64348E-01
N-HEX-02	0.22257E-01	0.86478E-01	0.26390E-02	0.30517E-01
N-HEP-02	0.17644E-01	0.71124E-01	0.13079E-02	0.18388E-01
N-OCT-02	0.14774E-01	0.60826E-01	0.70663E-03	0.11617E-01
N-NON-02	0.11480E-01	0.48022E-01	0.31826E-03	0.66274E-02

U-O-S BLOCK SECTION

BLOCK: FUELHEAT MODEL: HEATER (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
N-EIC-01	0.87713E-02	0.37018E-01	0.14307E-03	0.38648E-02
N-HEN-01	0.65630E-02	0.27840E-01	0.63735E-04	0.22894E-02
N-DOC-01	0.44103E-02	0.18761E-01	0.26708E-04	0.14236E-02
N-TRI-02	0.32691E-02	0.13934E-01	0.11388E-04	0.81732E-03
N-TET-02	0.23353E-02	0.99642E-02	0.49069E-05	0.49245E-03
N-PEN-03	0.17526E-02	0.74827E-02	0.21966E-05	0.29355E-03
N-HEX-03	0.11982E-02	0.51177E-02	0.92395E-06	0.18054E-03
N-HEP-03	0.89033E-03	0.38037E-02	0.38401E-06	0.10096E-03
N-OCT-03	0.31936E-03	0.13645E-02	0.87694E-07	0.64266E-04
N-NON-03	0.52811E-03	0.22567E-02	0.92756E-07	0.41103E-04
N-TRI-03	0.40852E-03	0.17458E-02	0.37979E-07	0.21755E-04
CARBO-02	0.15646E-06	0.15217E-07	0.19961E-06	13.117

BLOCK: LIQ2HX1 MODEL: HEATX

HOT SIDE:

INLET STREAM: DIESELHO

OUTLET STREAM: DIESELCO

```
10878      PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
10879      COLD SIDE:
10880      ----------
10881      INLET STREAM:             LIQ2
10882      OUTLET STREAM:            LIQ2WARM
10883      PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
10884
10885                         ***  MASS AND ENERGY BALANCE  ***
10886                                      IN              OUT        RELATIVE DIFF.
10887       TOTAL BALANCE
10888          MOLE(LBMOL/HR)            993.926         993.926         0.00000
10889          MASS(LB/HR   )           23385.3         23385.3          0.00000
10890          ENTHALPY(BTU/HR  )    -0.120436E+09   -0.120436E+09     0.00000
10891
10892                         ***  CO2 EQUIVALENT SUMMARY ***
10893       FEED STREAMS CO2E             526.170      LB/HR
10894       PRODUCT STREAMS CO2E          526.170      LB/HR
10895       NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
10896       UTILITIES CO2E PRODUCTION     0.00000      LB/HR
10897       TOTAL CO2E PRODUCTION         0.00000      LB/HR
10898    FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 40
10899
10900                                U-O-S BLOCK SECTION
10901
10902     BLOCK:  LIQ2HX1  MODEL: HEATX (CONTINUED)
10903
10904                              ***  INPUT DATA  ***
10905
10906      FLASH SPECS FOR HOT SIDE:
10907      TWO    PHASE      FLASH
10908      MAXIMUM NO. ITERATIONS                                    30
10909      CONVERGENCE TOLERANCE                                      0.000100000
10910
10911      FLASH SPECS FOR COLD SIDE:
10912      TWO    PHASE      FLASH
10913      MAXIMUM NO. ITERATIONS                                    30
10914      CONVERGENCE TOLERANCE                                      0.000100000
10915
10916      FLOW DIRECTION AND SPECIFICATION:
10917        COUNTERCURRENT   HEAT EXCHANGER
10918        SPECIFIED HOT APPROACH TEMP
10919        SPECIFIED VALUE                DELTA-C                  27.7000
10920        TEMPERATURE TOLERANCE          DELTA-C                   0.01000
10921        LMTD CORRECTION FACTOR                                   1.00000
10922
10923      PRESSURE SPECIFICATION:
10924        HOT  SIDE PRESSURE DROP        PSI                       0.0000
10925        COLD SIDE PRESSURE DROP        PSI                       0.0000
10926
10927      HEAT TRANSFER COEFFICIENT SPECIFICATION:
10928        HOT LIQUID    COLD LIQUID      BTU/HR-SQFT-R           149.6937
10929        HOT 2-PHASE   COLD LIQUID      BTU/HR-SQFT-R           149.6937
10930        HOT VAPOR     COLD LIQUID      BTU/HR-SQFT-R           149.6937
10931        HOT LIQUID    COLD 2-PHASE     BTU/HR-SQFT-R           149.6937
10932        HOT 2-PHASE   COLD 2-PHASE     BTU/HR-SQFT-R           149.6937
10933        HOT VAPOR     COLD 2-PHASE     BTU/HR-SQFT-R           149.6937
10934        HOT LIQUID    COLD VAPOR       BTU/HR-SQFT-R           149.6937
10935        HOT 2-PHASE   COLD VAPOR       BTU/HR-SQFT-R           149.6937
10936        HOT VAPOR     COLD VAPOR       BTU/HR-SQFT-R           149.6937
10937
10938                              ***  OVERALL RESULTS  ***
10939
10940      STREAMS:
10941                         ---------------------------------------
10942                         |                                     |
10943      DIESELHO  ----->|                HOT                  |-----> DIESELCO
```

```
  T=  1.7000D+02  |                                        |       T=  1.4770D+02
  P=  1.4504D+01  |                                        |       P=  1.4504D+01
  V=  0.0000D+00  |                                        |       V=  0.0000D+00
                  |                                        |
  LIQ2WARM  <-----|                COLD                    |<----- LIQ2
  T=  1.2288D+02  |                                        |       T=  1.2000D+02
  P=  3.6300D+02  |                                        |       P=  3.6300D+02
  V=  3.3738D-05  |                                        |       V=  0.0000D+00
                  ----------------------------------------
```


U-O-S BLOCK SECTION

BLOCK: LIQ2HX1 MODEL: HEATX (CONTINUED)

DUTY AND AREA:

CALCULATED HEAT DUTY	BTU/HR	105835.2527
CALCULATED (REQUIRED) AREA	SQFT	10.7451
ACTUAL EXCHANGER AREA	SQFT	10.7451
PER CENT OVER-DESIGN		0.0000

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY)	BTU/HR-SQFT-R	149.6937
UA (DIRTY)	BTU/HR-R	1608.4781

LOG-MEAN TEMPERATURE DIFFERENCE:

LMTD CORRECTION FACTOR		1.0000
LMTD (CORRECTED)	DELTA-C	36.5547
NUMBER OF SHELLS IN SERIES		1

PRESSURE DROP:

HOTSIDE, TOTAL	PSI	0.0000
COLDSIDE, TOTAL	PSI	0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

```
                                HOT
        ------------------------------------------------------------
        |                                                          |
HOT IN  |                          LIQ                             | HOT OUT
------> |                                                          |------>
 170.0  |                                                          |  147.7
        |                                                          |
COLDOUT |                          BOIL                            | COLDIN
<------ |                                                          |<------
 122.9  |                                                          |  120.0
        |                                                          |
        ------------------------------------------------------------
                                COLD
```

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY BTU/HR	AREA SQFT	LMTD DELT	AVERAGE U BTU/HR-SQFT-R	UA BTU/HR-R
1	105835.253	10.7451	36.5547	149.6937	1608.4781

U-O-S BLOCK SECTION

HEATX COLD-TQCU LIQ2HX1 TQCURV INLET

PRESSURE PROFILE:	CONSTANT2	
PRESSURE DROP:	0.0	PSI
PROPERTY OPTION SET:	NRTL	RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	363.0000	122.8791	3.3738-05
5039.7739	363.0000	122.7424	3.3157-05
1.0080+04	363.0000	122.6057	3.2581-05
1.5119+04	363.0000	122.4689	3.2010-05
2.0159+04	363.0000	122.3321	3.1443-05
2.5199+04	363.0000	122.1953	3.0882-05
3.0239+04	363.0000	122.0584	3.0326-05
3.5278+04	363.0000	121.9215	2.9774-05
4.0318+04	363.0000	121.7845	2.9227-05
4.5358+04	363.0000	121.6475	2.8685-05
5.0398+04	363.0000	121.5104	2.8148-05
5.5438+04	363.0000	121.3733	2.7616-05
6.0477+04	363.0000	121.2362	2.7088-05
6.5517+04	363.0000	121.0990	2.6565-05
7.0557+04	363.0000	120.9618	2.6046-05
7.5597+04	363.0000	120.8245	2.5532-05
8.0636+04	363.0000	120.6872	2.5023-05
8.5676+04	363.0000	120.5499	2.4518-05
9.0716+04	363.0000	120.4125	2.4017-05
9.5756+04	363.0000	120.2751	2.3521-05
1.0080+05	363.0000	120.1376	2.3030-05
1.0584+05	363.0000	120.0001	2.2543-05

U-O-S BLOCK SECTION

HEATX HOT-TQCUR LIQ2HX1 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	14.5038	170.0000	0.0
5039.7739	14.5038	168.9563	0.0
1.0080+04	14.5038	167.9108	0.0
1.5119+04	14.5038	166.8635	0.0
2.0159+04	14.5038	165.8144	0.0
2.5199+04	14.5038	164.7635	0.0
3.0239+04	14.5038	163.7108	0.0
3.5278+04	14.5038	162.6563	0.0
4.0318+04	14.5038	161.6000	0.0
4.5358+04	14.5038	160.5419	0.0

```
11076    !  5.0398+04 !    14.5038 !   159.4819 !     0.0    !
11077    !  5.5438+04 !    14.5038 !   158.4202 !     0.0    !
11078    !  6.0477+04 !    14.5038 !   157.3565 !     0.0    !
11079    !  6.5517+04 !    14.5038 !   156.2911 !     0.0    !
11080    !  7.0557+04 !    14.5038 !   155.2237 !     0.0    !
11081    !------------+------------+------------+------------!
11082    !  7.5597+04 !    14.5038 !   154.1546 !     0.0    !
11083    !  8.0636+04 !    14.5038 !   153.0835 !     0.0    !
11084    !  8.5676+04 !    14.5038 !   152.0106 !     0.0    !
11085    !  9.0716+04 !    14.5038 !   150.9358 !     0.0    !
11086    !  9.5756+04 !    14.5038 !   149.8592 !     0.0    !
11087    !------------+------------+------------+------------!
11088    !  1.0080+05 !    14.5038 !   148.7806 !     0.0    !
11089    !  1.0584+05 !    14.5038 !   147.7001 !     0.0    !
11090    ------------------------------------------------------

11091
11092    BLOCK:  LIQFLAH  MODEL: HEATER
11093    ------------------------------
11094      INLET STREAM:          FLASLIQ2
11095      OUTLET STREAM:         FLASHWRM
11096      PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
11097
11098                          ***  MASS AND ENERGY BALANCE  ***
11099                                       IN              OUT        RELATIVE DIFF.
11100    FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 44
11101
11102                                  U-O-S BLOCK SECTION
11103
11104    BLOCK:  LIQFLAH  MODEL: HEATER (CONTINUED)
11105       TOTAL BALANCE
11106          MOLE(LBMOL/HR)            1044.73         1044.73         0.00000
11107          MASS(LB/HR   )            27515.9         27515.9       -0.132214E-15
11108          ENTHALPY(BTU/HR  )     -0.130231E+09   -0.126958E+09   -0.251352E-01
11109
11110                          ***  CO2 EQUIVALENT SUMMARY ***
11111       FEED STREAMS CO2E             1409.26      LB/HR
11112       PRODUCT STREAMS CO2E          1409.26      LB/HR
11113       NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
11114       UTILITIES CO2E PRODUCTION     0.00000      LB/HR
11115       TOTAL CO2E PRODUCTION         0.00000      LB/HR
11116
11117                             ***  INPUT DATA  ***
11118      TWO    PHASE  TP  FLASH
11119      SPECIFIED TEMPERATURE                C                      120.000
11120      SPECIFIED PRESSURE                   PSIA                   363.000
11121      MAXIMUM NO. ITERATIONS                                       30
11122      CONVERGENCE TOLERANCE                                         0.000100000
11123
11124
11125
11126                               ***  RESULTS  ***
11127      OUTLET TEMPERATURE    C                                    120.00
11128      OUTLET PRESSURE       PSIA                                 363.00
11129      HEAT DUTY             BTU/HR                             0.32734E+07
11130      OUTLET VAPOR FRACTION                                    0.95338E-03
11131
11132
11133
11134      V-L PHASE EQUILIBRIUM :
11135
11136         COMP             F(I)          X(I)          Y(I)          K(I)
11137         WATER           0.92070       0.92150       0.82631E-01   0.89671E-01
11138         METHA-01        0.62413E-04   0.59336E-04   0.32869E-02    55.395
11139         ETHAN-01        0.49737E-04   0.42258E-04   0.78873E-02    186.65
11140         PROPA-01        0.19840E-03   0.19202E-03   0.68864E-02    35.864
11141         N-BUT-01        0.45721E-03   0.44577E-03   0.12438E-01    27.903
```

N-PEN-01	0.10278E-02	0.75804E-03	0.28369	374.25
N-HEX-01	0.21495E-02	0.19856E-02	0.17390	87.581
N-HEP-01	0.40205E-02	0.39590E-02	0.68527E-01	17.309
N-OCT-01	0.49652E-02	0.49609E-02	0.94027E-02	1.8953
N-NON-01	0.43702E-02	0.43711E-02	0.33786E-02	0.77295
N-DEC-01	0.40441E-02	0.40330E-02	0.15673E-01	3.8861
N-UND-01	0.35595E-02	0.35598E-02	0.32514E-02	0.91337
N-DOD-01	0.31336E-02	0.31355E-02	0.11877E-02	0.37878
N-TRI-01	0.27229E-02	0.27251E-02	0.39675E-03	0.14559
N-TET-01	0.23721E-02	0.23742E-02	0.17298E-03	0.72860E-01
N-PEN-02	0.20673E-02	0.20692E-02	0.35555E-05	0.17182E-02
N-HEX-02	0.17898E-02	0.17915E-02	0.20969E-04	0.11705E-01
N-HEP-02	0.15411E-02	0.15425E-02	0.34645E-06	0.22460E-03
N-OCT-02	0.13688E-02	0.13701E-02	0.12981E-06	0.94746E-04

U-O-S BLOCK SECTION

BLOCK: LIQFLAH MODEL: HEATER (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
N-NON-02	0.11773E-02	0.11785E-02	0.46600E-07	0.39543E-04
N-EIC-01	0.10338E-02	0.10347E-02	0.17089E-07	0.16515E-04
N-HEN-01	0.90933E-03	0.91020E-03	0.67101E-08	0.73722E-05
N-DOC-01	0.75618E-03	0.75690E-03	0.26305E-08	0.34754E-05
N-TRI-02	0.67960E-03	0.68025E-03	0.10474E-08	0.15398E-05
N-TET-02	0.59346E-03	0.59402E-03	0.44794E-09	0.75408E-06
N-PEN-03	0.51688E-03	0.51737E-03	0.19983E-09	0.38624E-06
N-HEX-03	0.44988E-03	0.45031E-03	0.85734E-10	0.19039E-06
N-HEP-03	0.39245E-03	0.39282E-03	0.35604E-10	0.90638E-07
N-OCT-03	0.33502E-03	0.33534E-03	0.95115E-11	0.28364E-07
N-NON-03	0.29673E-03	0.29701E-03	0.68871E-11	0.23188E-07
N-TRI-03	0.25844E-03	0.25869E-03	0.25407E-11	0.98217E-08
CARBO-01	0.81393E-05	0.80092E-05	0.14451E-03	18.043
HYDRO-01	0.19137E-02	0.16750E-02	0.25202	150.46
CARBO-02	0.30082E-01	0.30039E-01	0.75090E-01	2.4998

BLOCK: LUBEHEAT MODEL: HEATER

INLET STREAM: HYDROCAR
OUTLET STREAM: FEEDLUB
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	0.794034E-01	0.794034E-01	0.00000
MASS(LB/HR)	18.5699	18.5699	0.00000
ENTHALPY(BTU/HR)	-13077.3	-9115.56	-0.302948

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.551765E-01	LB/HR
PRODUCT STREAMS CO2E	0.551765E-01	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	C	350.000
SPECIFIED PRESSURE	PSIA	363.000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

U-O-S BLOCK SECTION

BLOCK: LUBEHEAT MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	C	350.00
OUTLET PRESSURE	PSIA	363.00
HEAT DUTY	BTU/HR	3961.7
OUTLET VAPOR FRACTION		0.95940E-01

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	0.56164E-01	0.40876E-02	0.54689	133.79
METHA-01	0.43664E-04	0.42807E-05	0.41478E-03	96.896
ETHAN-01	0.94268E-03	0.18288E-03	0.81025E-02	44.306
PROPA-01	0.16974E-02	0.56209E-03	0.12395E-01	22.053
N-BUT-01	0.53048E-02	0.25286E-02	0.31465E-01	12.444
N-PEN-01	0.69798E-02	0.45519E-02	0.29859E-01	6.5595
N-HEX-01	0.19441E-01	0.14646E-01	0.64625E-01	4.4126
N-HEP-01	0.12198E-01	0.10597E-01	0.27288E-01	2.5751
N-OCT-01	0.19221E-03	0.20947E-03	0.29566E-04	0.14115
N-NON-01	0.40663E-01	0.39442E-01	0.52172E-01	1.3228
N-DEC-01	0.67749E-02	0.70068E-02	0.45893E-02	0.65497
N-UND-01	0.58391E-02	0.60584E-02	0.37721E-02	0.62262
N-DOD-01	0.51061E-02	0.53949E-02	0.23847E-02	0.44204
N-TRI-01	0.48191E-02	0.51574E-02	0.16318E-02	0.31641
N-TET-01	0.43869E-02	0.47094E-02	0.13486E-02	0.28637
N-PEN-02	0.10554	0.11451	0.21025E-01	0.18361
N-HEX-02	0.33798E-02	0.36847E-02	0.50695E-03	0.13758
N-HEP-02	0.13016	0.14243	0.14588E-01	0.10242
N-OCT-02	0.13578	0.14894	0.11778E-01	0.79082E-01
N-NON-02	0.12592	0.13839	0.84137E-02	0.60798E-01
N-EIC-01	0.10166	0.11191	0.51120E-02	0.45680E-01
N-HEN-01	0.76315E-01	0.84098E-01	0.29763E-02	0.35391E-01
N-DOC-01	0.48976E-01	0.54014E-01	0.14970E-02	0.27714E-01
N-TRI-02	0.32924E-01	0.36335E-01	0.78083E-03	0.21490E-01
N-TET-02	0.20639E-01	0.22789E-01	0.38056E-03	0.16699E-01
N-PEN-03	0.12770E-01	0.14105E-01	0.18564E-03	0.13161E-01
N-HEX-03	0.81661E-02	0.90228E-02	0.93227E-04	0.10332E-01
N-HEP-03	0.52506E-02	0.58028E-02	0.46465E-04	0.80073E-02
N-OCT-03	0.34301E-03	0.37916E-03	0.23576E-05	0.62179E-02
N-NON-03	0.23540E-02	0.26023E-02	0.13721E-04	0.52727E-02
N-TRI-03	0.21800E-02	0.24106E-02	0.68517E-05	0.28423E-02
CARBO-01	0.71534E-05	0.49566E-06	0.69891E-04	141.00
HYDRO-01	0.16847E-02	0.30593E-04	0.17272E-01	564.56
CARBO-02	0.15391E-01	0.34112E-02	0.12828	37.607

U-O-S BLOCK SECTION

BLOCK: LUBEHX MODEL: HEATX

HOT SIDE:

INLET STREAM: LUBE
OUTLET STREAM: LUBEOUT
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

COLD SIDE:

INLET STREAM: LIQ2WARM

```
11274      OUTLET STREAM:            LIQ2WAMR
11275      PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS
11276
11277                          ***  MASS AND ENERGY BALANCE  ***
11278                                        IN              OUT        RELATIVE DIFF.
11279       TOTAL BALANCE
11280          MOLE(LBMOL/HR)            974.483         974.483         0.00000
11281          MASS(LB/HR   )            19356.8         19356.8         0.00000
11282          ENTHALPY(BTU/HR  )     -0.117440E+09   -0.117440E+09     0.00000
11283
11284                          ***  CO2 EQUIVALENT SUMMARY ***
11285       FEED STREAMS CO2E             526.181      LB/HR
11286       PRODUCT STREAMS CO2E          526.181      LB/HR
11287       NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
11288       UTILITIES CO2E PRODUCTION     0.00000      LB/HR
11289       TOTAL CO2E PRODUCTION         0.00000      LB/HR
11290
11291                             ***  INPUT DATA  ***
11292
11293      FLASH SPECS FOR HOT SIDE:
11294      TWO    PHASE      FLASH
11295      MAXIMUM NO. ITERATIONS                                    30
11296      CONVERGENCE TOLERANCE                                      0.000100000
11297
11298      FLASH SPECS FOR COLD SIDE:
11299      TWO    PHASE      FLASH
11300      MAXIMUM NO. ITERATIONS                                    30
11301      CONVERGENCE TOLERANCE                                      0.000100000
11302
11303      FLOW DIRECTION AND SPECIFICATION:
11304        COUNTERCURRENT   HEAT EXCHANGER
11305        SPECIFIED HOT APPROACH TEMP
11306        SPECIFIED VALUE                DELTA-C                27.7800
11307        TEMPERATURE TOLERANCE          DELTA-C                 0.01000
11308        LMTD CORRECTION FACTOR                                 1.00000
11309  FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/14/2019  PAGE 48
11310
11311                               U-O-S BLOCK SECTION
11312
11313     BLOCK:  LUBEHX   MODEL: HEATX (CONTINUED)
11314
11315      PRESSURE SPECIFICATION:
11316        HOT  SIDE PRESSURE DROP        PSI                     0.0000
11317        COLD SIDE PRESSURE DROP        PSI                     0.0000
11318
11319      HEAT TRANSFER COEFFICIENT SPECIFICATION:
11320        HOT LIQUID    COLD LIQUID      BTU/HR-SQFT-R          149.6937
11321        HOT 2-PHASE   COLD LIQUID      BTU/HR-SQFT-R          149.6937
11322        HOT VAPOR     COLD LIQUID      BTU/HR-SQFT-R          149.6937
11323        HOT LIQUID    COLD 2-PHASE     BTU/HR-SQFT-R          149.6937
11324        HOT 2-PHASE   COLD 2-PHASE     BTU/HR-SQFT-R          149.6937
11325        HOT VAPOR     COLD 2-PHASE     BTU/HR-SQFT-R          149.6937
11326        HOT LIQUID    COLD VAPOR       BTU/HR-SQFT-R          149.6937
11327        HOT 2-PHASE   COLD VAPOR       BTU/HR-SQFT-R          149.6937
11328        HOT VAPOR     COLD VAPOR       BTU/HR-SQFT-R          149.6937
11329
11330                               ***  OVERALL RESULTS  ***
11331
11332      STREAMS:
11333                      ----------------------------------------
11334                      |                                      |
11335      LUBE      ----->|                HOT                   |-----> LUBEOUT
11336      T=  3.5000D+02  |                                      |       T=  1.5066D+02
11337      P=  3.6259D+02  |                                      |       P=  3.6259D+02
11338      V=  0.0000D+00  |                                      |       V=  0.0000D+00
11339                      |                                      |
```

```
  LIQ2WAMR  <-----|                COLD                |<----- LIQ2WARM
  T=  1.2301D+02  |                                    |       T=  1.2288D+02
  P=  3.6300D+02  |                                    |       P=  3.6300D+02
  V=  3.4294D-05  |                                    |       V=  3.3738D-05
                  ------------------------------------
```

DUTY AND AREA:		
CALCULATED HEAT DUTY	BTU/HR	4773.7157
CALCULATED (REQUIRED) AREA	SQFT	0.1868
ACTUAL EXCHANGER AREA	SQFT	0.1868
PER CENT OVER-DESIGN		0.0000
HEAT TRANSFER COEFFICIENT:		
AVERAGE COEFFICIENT (DIRTY)	BTU/HR-SQFT-R	149.6937
UA (DIRTY)	BTU/HR-R	27.9648
LOG-MEAN TEMPERATURE DIFFERENCE:		
LMTD CORRECTION FACTOR		1.0000
LMTD (CORRECTED)	DELTA-C	94.8357
NUMBER OF SHELLS IN SERIES		1
PRESSURE DROP:		
HOTSIDE, TOTAL	PSI	0.0000
COLDSIDE, TOTAL	PSI	0.0000

U-O-S BLOCK SECTION

BLOCK: LUBEHX MODEL: HEATX (CONTINUED)

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

```
                                HOT
        ------------------------------------------------------------
        |                                                          |
HOT IN  |                         LIQ                              | HOT OUT
------> |                                                          |------>
 350.0  |                                                          |  150.7
        |                                                          |
COLDOUT |                         BOIL                             | COLDIN
<------ |                                                          |<------
 123.0  |                                                          |  122.9
        |                                                          |
        ------------------------------------------------------------
                                COLD
```

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY BTU/HR	AREA SQFT	LMTD DELT	AVERAGE U BTU/HR-SQFT-R	UA BTU/HR-R
1	4773.716	0.1868	94.8357	149.6937	27.9648

U-O-S BLOCK SECTION

HEATX COLD-TQCU LUBEHX TQCURV INLET

PRESSURE PROFILE:	CONSTANT2			
PRESSURE DROP:	0.0	PSI		
PROPERTY OPTION SET:	NRTL	RENON (NRTL) / IDEAL GAS		

DUTY	PRES	TEMP	VFRAC

BTU/HR	PSIA	C	
0.0	363.0000	123.0086	3.4294-05
227.3198	363.0000	123.0024	3.4268-05
454.6396	363.0000	122.9962	3.4241-05
681.9594	363.0000	122.9901	3.4215-05
909.2792	363.0000	122.9839	3.4188-05
1136.5990	363.0000	122.9778	3.4161-05
1363.9188	363.0000	122.9716	3.4135-05
1591.2386	363.0000	122.9654	3.4109-05
1818.5584	363.0000	122.9593	3.4082-05
2045.8782	363.0000	122.9531	3.4056-05
2273.1980	363.0000	122.9469	3.4029-05
2500.5178	363.0000	122.9408	3.4003-05
2727.8376	363.0000	122.9346	3.3976-05
2955.1574	363.0000	122.9285	3.3950-05
3182.4771	363.0000	122.9223	3.3923-05
3409.7969	363.0000	122.9161	3.3897-05
3637.1167	363.0000	122.9100	3.3871-05
3864.4365	363.0000	122.9038	3.3844-05
4091.7563	363.0000	122.8976	3.3818-05
4319.0761	363.0000	122.8915	3.3792-05
4546.3959	363.0000	122.8853	3.3765-05
4773.7157	363.0000	122.8791	3.3739-05

U-O-S BLOCK SECTION

HEATX HOT-TQCUR LUBEHX TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	C	
0.0	362.5943	350.0002	0.0
227.3198	362.5943	341.6005	0.0
454.6396	362.5943	333.0715	0.0
681.9594	362.5943	324.4072	0.0
909.2792	362.5943	316.0476	0.0
1136.5990	362.5943	307.3783	0.0
1363.9188	362.5943	298.5260	0.0
1591.2386	362.5943	289.5326	0.0
1818.5584	362.5943	280.4064	0.0
2045.8782	362.5943	271.1530	0.0
2273.1980	362.5943	261.8883	0.0
2500.5178	362.5943	252.4427	0.0
2727.8376	362.5943	242.8511	0.0
2955.1574	362.5943	233.2066	0.0

```
   !  3182.4771 !   362.5943 !   223.4561 !     0.0    !
   !------------+------------+------------+------------!
   !  3409.7969 !   362.5943 !   213.5132 !     0.0    !
   !  3637.1167 !   362.5943 !   203.4154 !     0.0    !
   !  3864.4365 !   362.5943 !   193.1987 !     0.0    !
   !  4091.7563 !   362.5943 !   182.8204 !     0.0    !
   !  4319.0761 !   362.5943 !   172.2696 !     0.0    !
   !------------+------------+------------+------------!
   !  4546.3959 !   362.5943 !   161.5470 !     0.0    !
   !  4773.7157 !   362.5943 !   150.6591 !     0.0    !
   ------------------------------------------------------

  BLOCK:  MIXER    MODEL: MIXER
  ------------------------------
    INLET STREAMS:         FLASHLQ3    LIQ1COLD    MIDALK2
    OUTLET STREAM:         COL1FEED
    PROPERTY OPTION SET:   NRTL      RENON (NRTL) / IDEAL GAS

                         ***  MASS AND ENERGY BALANCE  ***
                                      IN              OUT        RELATIVE DIFF.
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/14/2019  PAGE 52

                                U-O-S BLOCK SECTION

  BLOCK:  MIXER    MODEL: MIXER (CONTINUED)
     TOTAL BALANCE
        MOLE(LBMOL/HR)            168.008         168.008         0.00000
        MASS(LB/HR   )            12659.8         12659.8        0.143683E-15
        ENTHALPY(BTU/HR  )      -0.220308E+08   -0.220308E+08   -0.338189E-15

                         ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             3627.21      LB/HR
     PRODUCT STREAMS CO2E          3627.21      LB/HR
     NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
     UTILITIES CO2E PRODUCTION     0.00000      LB/HR
     TOTAL CO2E PRODUCTION         0.00000      LB/HR

                             ***  INPUT DATA  ***
    TWO    PHASE      FLASH
    MAXIMUM NO. ITERATIONS                                    30
    CONVERGENCE TOLERANCE                                      0.000100000
    OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                    04/14/2019  PAGE 53

                                  STREAM SECTION

  COL1FEED COLDFLAS DIESEL DIESELCO DIESELHO
  ------------------------------------------

  STREAM ID               COL1FEED   COLDFLAS   DIESEL     DIESELCO   DIESELHO
  FROM :                  MIXER      COOLER1    FLASH4     LIQ2HX1    ----
  TO   :                  DIST1      FLASH3     ----       ----       LIQ2HX1

  SUBSTREAM: MIXED
  PHASE:                  MIXED      MIXED      LIQUID     LIQUID     LIQUID
  COMPONENTS: LBMOL/HR
    WATER                 26.1699    19.6618  3.4091-02  3.4091-02  3.4091-02
    METHA-01               2.1849    15.1549     0.0        0.0        0.0
    ETHAN-01               0.9370    13.1681  3.0028-11  3.0028-11  3.0028-11
    PROPA-01               7.5746    11.2728  1.1079-08  1.1079-08  1.1079-08
    N-BUT-01               8.4020     9.5224  3.1113-05  3.1113-05  3.1113-05
    N-PEN-01               8.5590     7.6363  9.4775-02  9.4775-02  9.4775-02
    N-HEX-01               7.5351     5.3244     0.2451     0.2451     0.2451
    N-HEP-01               6.5975     2.3996     0.4013     0.4013     0.4013
    N-OCT-01               5.7298     0.5427     0.5465     0.5465     0.5465
    N-NON-01               4.5357     0.4244     0.7594     0.7594     0.7594
```

N-DEC-01	4.3390	0.1150	1.1721	1.1721	1.1721
N-UND-01	3.7695	5.1295-02	1.4047	1.4047	1.4047
N-DOD-01	3.2896	1.6206-02	1.6900	1.6900	1.6900
N-TRI-01	2.8496	5.2908-03	1.8506	1.8506	1.8506
N-TET-01	2.4796	1.8369-03	1.8210	1.8210	1.8210
N-PEN-02	2.0952	2.6627-04	1.7237	1.7237	1.7237
N-HEX-02	1.8696	1.6128-04	1.6961	1.6961	1.6961
N-HEP-02	1.4822	1.5907-05	1.3962	1.3962	1.3962
N-OCT-02	1.2411	4.5388-06	1.1946	1.1946	1.1946
N-NON-02	0.9644	1.1430-06	0.9435	0.9435	0.9435
N-EIC-01	0.7368	3.0983-07	0.7274	0.7274	0.7274
N-HEN-01	0.5513	1.0414-07	0.5471	0.5471	0.5471
N-DOC-01	0.3705	2.9378-08	0.3687	0.3687	0.3687
N-TRI-02	0.2746	8.4205-09	0.2739	0.2739	0.2739
N-TET-02	0.1962	3.4060-09	0.1958	0.1958	0.1958
N-PEN-03	0.1472	1.0964-09	0.1471	0.1471	0.1471
N-HEX-03	0.1007	4.2234-10	0.1006	0.1006	0.1006
N-HEP-03	7.4791-02	1.2961-10	7.4766-02	7.4766-02	7.4766-02
N-OCT-03	2.6827-02	2.3121-11	2.6822-02	2.6822-02	2.6822-02
N-NON-03	4.4363-02	9.7848-12	4.4357-02	4.4357-02	4.4357-02
N-TRI-03	3.4318-02	1.3857-12	3.4315-02	3.4315-02	3.4315-02
PENTA-01	0.0	0.0	0.0	0.0	0.0
CARBO-01	3.6493-03	1.1815	0.0	0.0	0.0
HYDRO-01	0.3346	3558.7065	0.0	0.0	0.0
CARBO-02	62.5064	364.4753	2.8602-07	2.8602-07	2.8602-07
TOTAL FLOW:					
LBMOL/HR	168.0075	4009.6608	19.5146	19.5146	19.5146
LB/HR	1.2660+04	2.6687+04	4046.6613	4046.6613	4046.6613
CUFT/HR	302.1934	4.5878+04	100.1580	97.6619	100.1580
STATE VARIABLES:					
TEMP C	39.8087	-54.0000	170.0000	147.7001	170.0000
PRES PSIA	362.5943	363.0000	14.5038	14.5038	14.5038
VFRAC	6.3651-03	0.9796	0.0	0.0	0.0
LFRAC	0.9936	2.0387-02	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0

STREAM SECTION

COL1FEED COLDFLAS DIESEL DIESELCO DIESEL (CONTINUED)

STREAM ID	COL1FEED	COLDFLAS	DIESEL	DIESELCO	DIESELHO
ENTHALPY:					
BTU/LBMOL	-1.3113+05	-1.7948+04	-1.4857+05	-1.5400+05	-1.4857+05
BTU/LB	-1740.2236	-2696.7168	-716.4832	-742.6369	-716.4832
BTU/HR	-2.2031+07	-7.1966+07	-2.8994+06	-3.0052+06	-2.8994+06
ENTROPY:					
BTU/LBMOL-R	-99.4847	-9.2999	-316.4626	-323.4042	-316.4626
BTU/LB-R	-1.3203	-1.3973	-1.5261	-1.5596	-1.5261
DENSITY:					
LBMOL/CUFT	0.5560	8.7398-02	0.1948	0.1998	0.1948
LB/CUFT	41.8929	0.5817	40.4028	41.4354	40.4028
AVG MW	75.3524	6.6556	207.3654	207.3654	207.3654

STREAM SECTION

FEEDLUB FLASHFE FLASHG2 FLASHGAS FLASHLQ3

STREAM ID	FEEDLUB	FLASHFE	FLASHG2	FLASHGAS	FLASHLQ3
FROM :	LUBEHEAT	DIST1	FLASH3	FLASH1	FLASH3
TO :	FLASHLUB	FUELHEAT	----	COOLER1	MIXER
SUBSTREAM: MIXED					

PHASE:	MIXED	LIQUID	VAPOR	VAPOR	LIQUID
COMPONENTS: LBMOL/HR					
WATER	4.4596-03	26.0980	1.6474-03	19.6618	19.6602
METHA-01	3.4670-06	2.4882-14	13.0266	15.1549	2.1283
ETHAN-01	7.4852-05	3.2543-08	12.2779	13.1681	0.8902
PROPA-01	1.3478-04	3.8830-06	3.8442	11.2728	7.4286
N-BUT-01	4.2122-04	5.0105-03	1.5093	9.5224	8.0131
N-PEN-01	5.5422-04	6.5656	0.1503	7.6363	7.4860
N-HEX-01	1.5437-03	7.5351	2.0968-02	5.3244	5.3034
N-HEP-01	9.6859-04	6.5975	5.1202-04	2.3996	2.3991
N-OCT-01	1.5262-05	5.7298	6.4962-05	0.5427	0.5427
N-NON-01	3.2288-03	4.5357	1.8934-06	0.4244	0.4244
N-DEC-01	5.3795-04	4.3390	2.5525-07	0.1150	0.1150
N-UND-01	4.6364-04	3.7695	3.3004-09	5.1295-02	5.1295-02
N-DOD-01	4.0544-04	3.2896	1.3469-10	1.6206-02	1.6206-02
N-TRI-01	3.8266-04	2.8496	1.0350-11	5.2908-03	5.2908-03
N-TET-01	3.4834-04	2.4796	5.6017-13	1.8369-03	1.8369-03
N-PEN-02	8.3805-03	2.0952	1.1393-14	2.6627-04	2.6627-04
N-HEX-02	2.6837-04	1.8696	1.3522-15	1.6128-04	1.6128-04
N-HEP-02	1.0335-02	1.4822	1.5585-17	1.5907-05	1.5907-05
N-OCT-02	1.0781-02	1.2411	8.1975-19	4.5388-06	4.5388-06
N-NON-02	9.9984-03	0.9644	2.4764-20	1.1430-06	1.1430-06
N-EIC-01	8.0724-03	0.7368	9.1755-22	3.0983-07	3.0983-07
N-HEN-01	6.0597-03	0.5513	1.0915-22	1.0414-07	1.0414-07
N-DOC-01	3.8888-03	0.3705	3.5739-24	2.9378-08	2.9378-08
N-TRI-02	2.6142-03	0.2746	1.0915-25	8.4205-09	8.4205-09
N-TET-02	1.6388-03	0.1962	1.8000-26	3.4060-09	3.4060-09
N-PEN-03	1.0140-03	0.1472	1.4142-27	1.0964-09	1.0964-09
N-HEX-03	6.4842-04	0.1007	1.6607-28	4.2234-10	4.2234-10
N-HEP-03	4.1691-04	7.4791-02	8.8409-30	1.2961-10	1.2961-10
N-OCT-03	2.7236-05	2.6827-02	1.8573-32	2.3121-11	2.3121-11
N-NON-03	1.8691-04	4.4363-02	3.6028-33	9.7848-12	9.7848-12
N-TRI-03	1.7310-04	3.4318-02	0.0	1.3857-12	0.0
PENTA-01	0.0	0.0	0.0	0.0	0.0
CARBO-01	5.6800-07	7.5748-15	1.1782	1.1815	3.3178-03
HYDRO-01	1.3377-04	1.1007-18	3558.4499	3558.7065	0.2566
CARBO-02	1.2221-03	1.3143-05	321.5193	364.4753	42.9560
TOTAL FLOW:					
LBMOL/HR	7.9403-02	84.0039	3911.9789	4009.6608	97.6819
LB/HR	18.5699	8877.6718	2.2205+04	2.6687+04	4482.0588
CUFT/HR	0.8094	204.8792	4.4454+04	6.9125+04	81.9321
STATE VARIABLES:					
TEMP C	350.0000	63.1728	-59.6022	50.4573	-59.6022
PRES PSIA	363.0000	14.7000	363.0000	362.5943	363.0000
VFRAC	9.5940-02	0.0	1.0000	1.0000	0.0
LFRAC	0.9041	1.0000	0.0	0.0	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0

STREAM SECTION

FEEDLUB FLASHFE FLASHG2 FLASHGAS FLASHLQ (CONTINUED)

STREAM ID	FEEDLUB	FLASHFE	FLASHG2	FLASHGAS	FLASHLQ3
ENTHALPY:					
BTU/LBMOL	-1.1480+05	-1.2402+05	-1.5267+04	-1.6353+04	-1.2937+05
BTU/LB	-490.8773	-1173.4900	-2689.6834	-2457.0778	-2819.4485
BTU/HR	-9115.5586	-1.0418+07	-5.9723+07	-6.5571+07	-1.2637+07
ENTROPY:					
BTU/LBMOL-R	-297.9880	-179.7976	-8.2450	-5.9919	-61.8887
BTU/LB-R	-1.2742	-1.7013	-1.4526	-0.9003	-1.3488
DENSITY:					
LBMOL/CUFT	9.8096-02	0.4100	8.8000-02	5.8006-02	1.1922
LB/CUFT	22.9415	43.3313	0.4995	0.3861	54.7045
AVG MW	233.8683	105.6816	5.6760	6.6556	45.8842

STREAM SECTION

FLASHWRM FLASLIQ2 FTPROD FUELFLAS GASES

STREAM ID	FLASHWRM	FLASLIQ2	FTPROD	FUELFLAS	GASES
FROM :	LIQFLAH	FLASH1	----	FUELHEAT	DIST1
TO :	DECANT1	LIQFLAH	FLASH1	FLASH4	----
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	MIXED	MIXED	VAPOR
COMPONENTS: LBMOL/HR					
WATER	961.8792	961.8792	981.5458	26.0980	7.1945-02
METHA-01	6.5205-02	6.5205-02	15.2201	2.4882-14	2.1849
ETHAN-01	5.1962-02	5.1962-02	13.2201	3.2543-08	0.9370
PROPA-01	0.2073	0.2073	11.4801	3.8830-06	7.5746
N-BUT-01	0.4777	0.4777	10.0001	5.0105-03	8.3970
N-PEN-01	1.0738	1.0738	8.7101	6.5656	1.9934
N-HEX-01	2.2457	2.2457	7.5700	7.5351	3.1853-06
N-HEP-01	4.2004	4.2004	6.6000	6.5975	1.6538-11
N-OCT-01	5.1873	5.1873	5.7300	5.7298	5.4778-13
N-NON-01	4.5656	4.5656	4.9900	4.5357	2.1713-17
N-DEC-01	4.2250	4.2250	4.3400	4.3390	3.9026-21
N-UND-01	3.7187	3.7187	3.7700	3.7695	1.2753-25
N-DOD-01	3.2738	3.2738	3.2900	3.2896	1.3209-29
N-TRI-01	2.8447	2.8447	2.8500	2.8496	5.9358-33
N-TET-01	2.4782	2.4782	2.4800	2.4796	0.0
N-PEN-02	2.1597	2.1597	2.1600	2.0952	0.0
N-HEX-02	1.8698	1.8698	1.8700	1.8696	0.0
N-HEP-02	1.6100	1.6100	1.6100	1.4822	0.0
N-OCT-02	1.4300	1.4300	1.4300	1.2411	0.0
N-NON-02	1.2300	1.2300	1.2300	0.9644	0.0
N-EIC-01	1.0800	1.0800	1.0800	0.7368	0.0
N-HEN-01	0.9500	0.9500	0.9500	0.5513	0.0
N-DOC-01	0.7900	0.7900	0.7900	0.3705	0.0
N-TRI-02	0.7100	0.7100	0.7100	0.2746	0.0
N-TET-02	0.6200	0.6200	0.6200	0.1962	0.0
N-PEN-03	0.5400	0.5400	0.5400	0.1472	0.0
N-HEX-03	0.4700	0.4700	0.4700	0.1007	0.0
N-HEP-03	0.4100	0.4100	0.4100	7.4791-02	0.0
N-OCT-03	0.3500	0.3500	0.3500	2.6827-02	0.0
N-NON-03	0.3100	0.3100	0.3100	4.4363-02	0.0
N-TRI-03	0.2700	0.2700	0.2700	3.4318-02	0.0
PENTA-01	0.0	0.0	0.0	0.0	0.0
CARBO-01	8.5034-03	8.5034-03	1.1900	7.5748-15	3.6493-03
HYDRO-01	1.9993	1.9993	3560.7011	1.1007-18	0.3346
CARBO-02	31.4274	31.4274	395.9023	1.3143-05	62.5064
TOTAL FLOW:					
LBMOL/HR	1044.7292	1044.7292	5054.3900	84.0039	84.0036
LB/HR	2.7516+04	2.7516+04	5.4203+04	8877.6718	3782.0948
CUFT/HR	606.4228	527.3148	7.7611+04	3.7572+04	2.7074+04
STATE VARIABLES:					
TEMP C	120.0000	50.4573	80.0000	170.0000	-27.8774
PRES PSIA	363.0000	362.5943	362.5943	14.7000	14.7000
VFRAC	9.5338-04	0.0	0.8116	0.7660	1.0000
LFRAC	0.9990	1.0000	0.1884	0.2340	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0

STREAM SECTION

FLASHWRM FLASLIQ2 FTPROD FUELFLAS GASES (CONTINUED)

STREAM ID	FLASHWRM	FLASLIQ2	FTPROD	FUELFLAS	GASES

ENTHALPY:					
BTU/LBMOL	-1.2152+05	-1.2466+05	-3.7888+04	-1.0053+05	-1.3923+05
BTU/LB	-4613.9776	-4732.9411	-3533.0932	-951.2508	-3092.3867
BTU/HR	-1.2696+08	-1.3023+08	-1.9150+08	-8.4449+06	-1.1696+07
ENTROPY:					
BTU/LBMOL-R	-44.2740	-48.8013	-13.4797	-145.0572	-17.9360
BTU/LB-R	-1.6810	-1.8529	-1.2570	-1.3726	-0.3984
DENSITY:					
LBMOL/CUFT	1.7228	1.9812	6.5124-02	2.2358-03	3.1027-03
LB/CUFT	45.3742	52.1812	0.6984	0.2363	0.1397
AVG MW	26.3379	26.3379	10.7239	105.6816	45.0230

STREAM SECTION

GASOLINE HYDROCAR LIQ1COLD LIQ2 LIQ2HOT

STREAM ID	GASOLINE	HYDROCAR	LIQ1COLD	LIQ2	LIQ2HOT
FROM :	FLASH4	DECANT2	DECANT1	DECANT1	DECANTH
TO :	----	LUBEHEAT	MIXER	LIQ2HX1	DECANT2
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	LIQUID	LIQUID	MIXED
COMPONENTS: LBMOL/HR					
WATER	26.0639	4.4596-03	6.5056	955.3736	955.3736
METHA-01	0.0	3.4670-06	5.6664-02	8.5405-03	8.5405-03
ETHAN-01	3.2513-08	7.4852-05	4.6693-02	5.2687-03	5.2687-03
PROPA-01	3.8720-06	1.3478-04	0.1460	6.1310-02	6.1310-02
N-BUT-01	4.9793-03	4.2122-04	0.3886	8.9026-02	8.9026-02
N-PEN-01	6.4708	5.5422-04	1.0728	9.8640-04	9.8640-04
N-HEX-01	7.2900	1.5437-03	2.2312	1.4452-02	1.4452-02
N-HEP-01	6.1961	9.6859-04	4.1982	2.2319-03	2.2319-03
N-OCT-01	5.1833	1.5262-05	5.1871	1.7257-04	1.7257-04
N-NON-01	3.7763	3.2288-03	4.1110	0.4547	0.4547
N-DEC-01	3.1669	5.3795-04	4.2239	1.0754-03	1.0754-03
N-UND-01	2.3648	4.6364-04	3.7182	5.2257-04	5.2257-04
N-DOD-01	1.5996	4.0544-04	3.2733	4.6746-04	4.6746-04
N-TRI-01	0.9989	3.8266-04	2.8443	4.5646-04	4.5646-04
N-TET-01	0.6585	3.4834-04	2.4777	4.4025-04	4.4025-04
N-PEN-02	0.3715	8.3805-03	2.0948	6.4967-02	6.4967-02
N-HEX-02	0.1735	2.6837-04	1.8695	3.6398-04	3.6398-04
N-HEP-02	8.5971-02	1.0335-02	1.4821	0.1279	0.1279
N-OCT-02	4.6487-02	1.0781-02	1.2410	0.1890	0.1890
N-NON-02	2.0935-02	9.9984-03	0.9643	0.2657	0.2657
N-EIC-01	9.4134-03	8.0724-03	0.7368	0.3432	0.3432
N-HEN-01	4.1944-03	6.0597-03	0.5513	0.3987	0.3987
N-DOC-01	1.7577-03	3.8888-03	0.3705	0.4195	0.4195
N-TRI-02	7.4957-04	2.6142-03	0.2746	0.4354	0.4354
N-TET-02	3.2301-04	1.6388-03	0.1962	0.4238	0.4238
N-PEN-03	1.4464-04	1.0140-03	0.1472	0.3928	0.3928
N-HEX-03	6.0816-05	6.4842-04	0.1007	0.3693	0.3693
N-HEP-03	2.5275-05	4.1691-04	7.4791-02	0.3352	0.3352
N-OCT-03	5.7752-06	2.7236-05	2.6827-02	0.3232	0.3232
N-NON-03	6.1050-06	1.8691-04	4.4363-02	0.2656	0.2656
N-TRI-03	2.4974-06	1.7310-04	3.4318-02	0.2357	0.2357
PENTA-01	0.0	0.0	0.0	0.0	0.0
CARBO-01	0.0	5.6800-07	3.3101-04	8.1724-03	8.1724-03
HYDRO-01	0.0	1.3377-04	7.7921-02	1.9214	1.9214
CARBO-02	1.2857-05	1.2221-03	19.5495	11.8779	11.8779
TOTAL FLOW:					
LBMOL/HR	64.4893	7.9403-02	70.3180	974.4112	974.4112
LB/HR	4831.0105	18.5699	8177.2946	1.9339+04	1.9339+04
CUFT/HR	3.8062+04	0.4605	201.7907	370.9160	530.2881
STATE VARIABLES:					

TEMP	C	170.0000	195.0000	120.0000	120.0000	195.0000
PRES	PSIA	14.5038	362.5943	363.0000	363.0000	363.0000
VFRAC		1.0000	0.0	0.0	0.0	4.6545-03
LFRAC		0.0	1.0000	1.0000	1.0000	0.9953
SFRAC		0.0	0.0	0.0	0.0	0.0

STREAM SECTION

GASOLINE HYDROCAR LIQ1COLD LIQ2 LIQ2HOT (CONTINUED)

STREAM ID	GASOLINE	HYDROCAR	LIQ1COLD	LIQ2	LIQ2HOT
ENTHALPY:					
BTU/LBMOL	-8.5951+04	-1.6469+05	-1.3358+05	-1.2062+05	-1.1749+05
BTU/LB	-1147.3566	-704.2187	-1148.6912	-6077.8414	-5919.8218
BTU/HR	-5.5429+06	-1.3077+04	-9.3932+06	-1.1754+08	-1.1448+08
ENTROPY:					
BTU/LBMOL-R	-93.1116	-348.3273	-157.7795	-35.8176	-31.9972
BTU/LB-R	-1.2429	-1.4894	-1.3568	-1.8047	-1.6122
DENSITY:					
LBMOL/CUFT	1.6943-03	0.1724	0.3485	2.6270	1.8375
LB/CUFT	0.1269	40.3257	40.5236	52.1375	36.4682
AVG MW	74.9118	233.8683	116.2901	19.8465	19.8465

STREAM SECTION

LIQ2WAMR LIQ2WARM LUBE LUBEOUT MIDALK

STREAM ID	LIQ2WAMR	LIQ2WARM	LUBE	LUBEOUT	MIDALK
FROM :	LUBEHX	LIQ2HX1	FLASHLUB	LUBEHX	FLASHLUB
TO :	DECANTH	LUBEHX	LUBEHX	----	----
CONV. MAX. REL. ERR:	-5.1346-08	0.0	0.0	0.0	0.0
SUBSTREAM: MIXED					
PHASE:	MIXED	MIXED	LIQUID	LIQUID	VAPOR
COMPONENTS: LBMOL/HR					
WATER	955.3736	955.3736	2.9292-04	2.9292-04	4.1667-03
METHA-01	8.5405-03	8.5405-03	3.0681-07	3.0681-07	3.1602-06
ETHAN-01	5.2687-03	5.2687-03	1.3110-05	1.3110-05	6.1743-05
PROPA-01	6.1310-02	6.1310-02	4.0303-05	4.0303-05	9.4475-05
N-BUT-01	8.9026-02	8.9026-02	1.8135-04	1.8135-04	2.3987-04
N-PEN-01	9.8640-04	9.8640-04	3.2652-04	3.2652-04	2.2770-04
N-HEX-01	1.4452-02	1.4452-02	1.0508-03	1.0508-03	4.9287-04
N-HEP-01	2.2319-03	2.2319-03	7.6042-04	7.6042-04	2.0817-04
N-OCT-01	1.7257-04	1.7257-04	1.5036-05	1.5036-05	2.2638-07
N-NON-01	0.4547	0.4547	2.8308-03	2.8308-03	3.9802-04
N-DEC-01	1.0754-03	1.0754-03	5.0292-04	5.0292-04	3.5028-05
N-UND-01	5.2257-04	5.2257-04	4.3486-04	4.3486-04	2.8781-05
N-DOD-01	4.6746-04	4.6746-04	3.8724-04	3.8724-04	1.8196-05
N-TRI-01	4.5646-04	4.5646-04	3.7020-04	3.7020-04	1.2452-05
N-TET-01	4.4025-04	4.4025-04	3.3805-04	3.3805-04	1.0291-05
N-PEN-02	6.4967-02	6.4967-02	8.2200-03	8.2200-03	1.6043-04
N-HEX-02	3.6398-04	3.6398-04	2.6450-04	2.6450-04	3.8684-06
N-HEP-02	0.1279	0.1279	1.0224-02	1.0224-02	1.1131-04
N-OCT-02	0.1890	0.1890	1.0691-02	1.0691-02	8.9874-05
N-NON-02	0.2657	0.2657	9.9342-03	9.9342-03	6.4201-05
N-EIC-01	0.3432	0.3432	8.0334-03	8.0334-03	3.9007-05
N-HEN-01	0.3987	0.3987	6.0370-03	6.0370-03	2.2711-05
N-DOC-01	0.4195	0.4195	3.8774-03	3.8774-03	1.1423-05
N-TRI-02	0.4354	0.4354	2.6083-03	2.6083-03	5.9582-06
N-TET-02	0.4238	0.4238	1.6359-03	1.6359-03	2.9039-06
N-PEN-03	0.3928	0.3928	1.0126-03	1.0126-03	1.4165-06

N-HEX-03	0.3693	0.3693	6.4771-04	6.4771-04	7.1138-07
N-HEP-03	0.3352	0.3352	4.1656-04	4.1656-04	3.5456-07
N-OCT-03	0.3232	0.3232	2.7218-05	2.7218-05	1.7990-08
N-NON-03	0.2656	0.2656	1.8681-04	1.8681-04	1.0470-07
N-TRI-03	0.2357	0.2357	1.7304-04	1.7304-04	5.2282-08
PENTA-01	0.0	0.0	0.0	0.0	0.0
CARBO-01	8.1724-03	8.1724-03	3.5525-08	3.5525-08	5.3248-07
HYDRO-01	1.9214	1.9214	2.1925-06	2.1925-06	1.3158-04
CARBO-02	11.8779	11.8779	2.4453-04	2.4453-04	9.7761-04
TOTAL FLOW:					
LBMOL/HR	974.4112	974.4112	7.1782-02	7.1782-02	7.6217-03
LB/HR	1.9339+04	1.9339+04	18.1568	18.1568	0.4132
CUFT/HR	373.2092	373.1280	0.5568	0.4249	0.2530

STREAM SECTION

LIQ2WAMR LIQ2WARM LUBE LUBEOUT MIDALK (CONTINUED)

STREAM ID	LIQ2WAMR	LIQ2WARM	LUBE	LUBEOUT	MIDALK
STATE VARIABLES:					
TEMP C	123.0086	122.8791	350.0000	150.6591	350.0000
PRES PSIA	363.0000	363.0000	362.5943	362.5943	362.5943
VFRAC	3.4294-05	3.3738-05	0.0	0.0	1.0000
LFRAC	1.0000	1.0000	1.0000	1.0000	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.2051+05	-1.2052+05	-1.1720+05	-1.8370+05	-9.2218+04
BTU/LB	-6072.1219	-6072.3687	-463.3356	-726.2522	-1701.1722
BTU/HR	-1.1743+08	-1.1743+08	-8412.6782	-1.3186+04	-702.8633
ENTROPY:					
BTU/LBMOL-R	-35.6635	-35.6701	-324.3154	-394.4604	-50.0311
BTU/LB-R	-1.7970	-1.7973	-1.2822	-1.5595	-0.9229
DENSITY:					
LBMOL/CUFT	2.6109	2.6115	0.1289	0.1690	3.0123-02
LB/CUFT	51.8171	51.8284	32.6080	42.7355	1.6329
AVG MW	19.8465	19.8465	252.9444	252.9444	54.2088

STREAM SECTION

MIDALK2 WATEROUT

STREAM ID	MIDALK2	WATEROUT
FROM :	----	DECANT2
TO :	MIXER	----
SUBSTREAM: MIXED		
PHASE:	MIXED	LIQUID
COMPONENTS: LBMOL/HR		
WATER	4.1667-03	955.3692
METHA-01	3.1602-06	8.5370-03
ETHAN-01	6.1743-05	5.1938-03
PROPA-01	9.4475-05	6.1175-02
N-BUT-01	2.3987-04	8.8605-02
N-PEN-01	2.2770-04	4.3218-04
N-HEX-01	4.9287-04	1.2908-02
N-HEP-01	2.0817-04	1.2634-03
N-OCT-01	2.2638-07	1.5730-04
N-NON-01	3.9802-04	0.4515
N-DEC-01	3.5028-05	5.3743-04
N-UND-01	2.8781-05	5.8934-05
N-DOD-01	1.8196-05	6.2020-05
N-TRI-01	1.2452-05	7.3808-05

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  N-TET-01            1.0291-05  9.1916-05
  N-PEN-02            1.6043-04  5.6586-02
  N-HEX-02            3.8684-06  9.5613-05
  N-HEP-02            1.1131-04     0.1176
  N-OCT-02            8.9874-05     0.1782
  N-NON-02            6.4201-05     0.2557
  N-EIC-01            3.9007-05     0.3351
  N-HEN-01            2.2711-05     0.3926
  N-DOC-01            1.1423-05     0.4156
  N-TRI-02            5.9582-06     0.4328
  N-TET-02            2.9039-06     0.4222
  N-PEN-03            1.4165-06     0.3918
  N-HEX-03            7.1138-07     0.3687
  N-HEP-03            3.5456-07     0.3348
  N-OCT-03            1.7990-08     0.3231
  N-NON-03            1.0470-07     0.2655
  N-TRI-03            5.2282-08     0.2355
  PENTA-01               0.0        0.0
  CARBO-01            5.3248-07  8.1718-03
  HYDRO-01            1.3158-04     1.9212
  CARBO-02            9.7761-04    11.8767
 TOTAL FLOW:
  LBMOL/HR            7.6217-03   974.3318
  LB/HR                  0.4132  1.9320+04
  CUFT/HR                0.2356   419.8908
 STATE VARIABLES:
  TEMP   C             350.0000   195.0000
  PRES   PSIA          362.5943   362.5943
  VFRAC                  0.9192     0.0
  LFRAC               8.0755-02     1.0000
  SFRAC                  0.0        0.0
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 64

                                STREAM SECTION

 MIDALK2 WATEROUT (CONTINUED)

 STREAM ID               MIDALK2    WATEROUT

 ENTHALPY:
  BTU/LBMOL          -9.2461+04 -1.1752+05
  BTU/LB             -1705.6515 -5926.5989
  BTU/HR              -704.7140 -1.1450+08
 ENTROPY:
  BTU/LBMOL-R          -50.8117   -32.0144
  BTU/LB-R              -0.9373    -1.6145
 DENSITY:
  LBMOL/CUFT          3.2349-02     2.3204
  LB/CUFT                1.7536    46.0121
 AVG MW                  54.2088    19.8290
FF ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                  04/14/2019  PAGE 65

                          PHYSICAL PROPERTY TABLES SECTION

 FLASH CURVE TABLE:  BINRY-1
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   PROPERTIES ALONG A FLASH CURVE FOR THE MIXTURE:  (LBMOL/HR    )
       METHA-01  1.000     , CARBO-02  1.000     ,

   STATE SPECIFICATIONS:
       VAPOR FRACTION:     0.000

   VARIED VARIABLE(S):    PRES      MOLEFRAC

   PROPERTY SET(S):       $PS-TXY
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3 PHASE PV FLASHES WERE PERFORMED.

PROPERTY OPTION SET: NRTL RENON (NRTL) / IDEAL GAS

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES	MOLEFRAC	TEMP	KVL	KVL	GAMMA
		TOTAL	TOTAL	TOTAL	LIQUID 1
	CARBO-02		METHA-01	CARBO-02	METHA-01
PSIA		C			
14.6959	0.0	-161.4840	1.0000	3.9277-02	1.0000
14.6959	2.0000-02	-161.4806	1.0003	3.7719-02	1.0000
14.6959	4.0000-02	-161.4806	1.0003	3.7720-02	1.0000
14.6959	6.0000-02	-161.4806	1.0003	3.7720-02	1.0000
14.6959	8.0000-02	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.1000	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.1200	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.1400	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.1600	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.1800	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.2000	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.2200	-161.4806	1.0003	3.7720-02	1.0000
14.6959	0.2400	-161.4592	1.3158	4.7258-05	1.3131
14.6959	0.2600	-160.6595	1.3513	5.9993-05	1.2633
14.6959	0.2800	-159.7220	1.3889	7.8723-05	1.2041
14.6959	0.3000	-158.6478	1.4285	1.0615-04	1.1379
14.6959	0.3200	-157.4374	1.4705	1.4637-04	1.0668
14.6959	0.3400	-156.0901	1.5150	2.0562-04	0.9928
14.6959	0.3600	-154.6044	1.5623	2.9332-04	0.9178
14.6959	0.3800	-152.9780	1.6126	4.2383-04	0.8432
14.6959	0.4000	-151.2073	1.6663	6.1895-04	0.7704
14.6959	0.4200	-149.2881	1.7235	9.1198-04	0.7002
14.6959	0.4400	-147.2150	1.7847	1.3537-03	0.6335
14.6959	0.4600	-144.9818	1.8501	2.0218-03	0.5707
14.6959	0.4800	-142.5816	1.9203	3.0347-03	0.5121
14.6959	0.5000	-140.0070	1.9954	4.5732-03	0.4580
14.6959	0.5200	-137.2506	2.0758	6.9124-03	0.4083
14.6959	0.5400	-134.3061	2.1616	1.0468-02	0.3630
14.6959	0.5600	-131.1696	2.2525	1.5860-02	0.3219
14.6959	0.5800	-127.8420	2.3478	2.4000-02	0.2849
14.6959	0.6000	-124.3328	2.4457	3.6192-02	0.2517
14.6959	0.6200	-120.6651	2.5431	5.4207-02	0.2220
14.6959	0.6400	-116.8816	2.6350	8.0292-02	0.1955
14.6959	0.6600	-113.0498	2.7141	0.1170	0.1721
14.6959	0.6800	-109.2629	2.7711	0.1665	0.1514

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES	MOLEFRAC	TEMP	KVL	KVL	GAMMA
		TOTAL	TOTAL	TOTAL	LIQUID 1
	CARBO-02		METHA-01	CARBO-02	METHA-01
PSIA		C			
14.6959	0.7000	-105.6325	2.7963	0.2302	0.1332
14.6959	0.7200	-102.2715	2.7814	0.3072	0.1172
14.6959	0.7400	-99.2732	2.7226	0.3948	0.1032
14.6959	0.7600	-96.6948	2.6216	0.4879	9.0938-02
14.6959	0.7800	-94.5531	2.4850	0.5812	8.0199-02
14.6959	0.8000	-92.8303	2.3223	0.6694	7.0793-02
14.6959	0.8200	-91.4857	2.1439	0.7489	6.2547-02
14.6959	0.8400	-90.4677	1.9594	0.8173	5.5311-02
14.6959	0.8600	-89.7218	1.7762	0.8736	4.8954-02
14.6959	0.8800	-89.1966	1.6000	0.9182	4.3365-02
14.6959	0.9000	-88.8461	1.4344	0.9517	3.8445-02
14.6959	0.9200	-88.6311	1.2814	0.9755	3.4110-02
14.6959	0.9400	-88.5185	1.1419	0.9909	3.0288-02
14.6959	0.9600	-88.4814	1.0159	0.9993	2.6915-02
14.6959	0.9800	-88.4980	0.9030	1.0020	2.3936-02
14.6959	1.0000	-88.5508	0.8023	1.0000	2.1304-02

PRES	MOLEFRAC	GAMMA	GAMMA	GAMMA	KVL2
		LIQUID 1	LIQUID 2	LIQUID 2	TOTAL
	CARBO-02	CARBO-02	METHA-01	CARBO-02	METHA-01
PSIA					
14.6959	0.0	53.5264	MISSING	MISSING	MISSING
14.6959	2.0000-02	51.3754	1.3144	6.3953-02	1.3148
14.6959	4.0000-02	51.3754	1.3144	6.3952-02	1.3148
14.6959	6.0000-02	51.3754	1.3144	6.3951-02	1.3148
14.6959	8.0000-02	51.3754	1.3144	6.3949-02	1.3148
14.6959	0.1000	51.3754	1.3144	6.3946-02	1.3148
14.6959	0.1200	51.3754	1.3144	6.3954-02	1.3148
14.6959	0.1400	51.3754	1.3144	6.3954-02	1.3148
14.6959	0.1600	51.3754	1.3144	6.3954-02	1.3148
14.6959	0.1800	51.3754	1.3144	6.3954-02	1.3148

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES	MOLEFRAC	GAMMA	GAMMA	GAMMA	KVL2
		LIQUID 1	LIQUID 2	LIQUID 2	TOTAL
	CARBO-02	CARBO-02	METHA-01	CARBO-02	METHA-01
PSIA					
14.6959	0.2000	51.3754	1.3144	6.3954-02	1.3148
14.6959	0.2200	51.3754	1.3144	6.3954-02	1.3148
14.6959	0.2400	6.4142-02	MISSING	MISSING	MISSING

14.6959	0.2600	7.1513-02	MISSING	MISSING	MISSING
14.6959	0.2800	8.0778-02	MISSING	MISSING	MISSING
14.6959	0.3000	9.2010-02	MISSING	MISSING	MISSING
14.6959	0.3200	0.1053	MISSING	MISSING	MISSING
14.6959	0.3400	0.1208	MISSING	MISSING	MISSING
14.6959	0.3600	0.1385	MISSING	MISSING	MISSING
14.6959	0.3800	0.1585	MISSING	MISSING	MISSING
14.6959	0.4000	0.1809	MISSING	MISSING	MISSING
14.6959	0.4200	0.2057	MISSING	MISSING	MISSING
14.6959	0.4400	0.2328	MISSING	MISSING	MISSING
14.6959	0.4600	0.2622	MISSING	MISSING	MISSING
14.6959	0.4800	0.2938	MISSING	MISSING	MISSING
14.6959	0.5000	0.3273	MISSING	MISSING	MISSING
14.6959	0.5200	0.3626	MISSING	MISSING	MISSING
14.6959	0.5400	0.3993	MISSING	MISSING	MISSING
14.6959	0.5600	0.4374	MISSING	MISSING	MISSING
14.6959	0.5800	0.4763	MISSING	MISSING	MISSING
14.6959	0.6000	0.5158	MISSING	MISSING	MISSING
14.6959	0.6200	0.5556	MISSING	MISSING	MISSING
14.6959	0.6400	0.5953	MISSING	MISSING	MISSING
14.6959	0.6600	0.6345	MISSING	MISSING	MISSING
14.6959	0.6800	0.6729	MISSING	MISSING	MISSING
14.6959	0.7000	0.7102	MISSING	MISSING	MISSING
14.6959	0.7200	0.7461	MISSING	MISSING	MISSING
14.6959	0.7400	0.7803	MISSING	MISSING	MISSING
14.6959	0.7600	0.8125	MISSING	MISSING	MISSING
14.6959	0.7800	0.8425	MISSING	MISSING	MISSING
14.6959	0.8000	0.8702	MISSING	MISSING	MISSING
14.6959	0.8200	0.8953	MISSING	MISSING	MISSING
14.6959	0.8400	0.9177	MISSING	MISSING	MISSING
14.6959	0.8600	0.9375	MISSING	MISSING	MISSING
14.6959	0.8800	0.9545	MISSING	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES	MOLEFRAC	GAMMA	GAMMA	GAMMA	KVL2
		LIQUID 1	LIQUID 2	LIQUID 2	TOTAL
	CARBO-02	CARBO-02	METHA-01	CARBO-02	METHA-01
PSIA					
14.6959	0.9000	0.9687	MISSING	MISSING	MISSING
14.6959	0.9200	0.9802	MISSING	MISSING	MISSING
14.6959	0.9400	0.9890	MISSING	MISSING	MISSING
14.6959	0.9600	0.9952	MISSING	MISSING	MISSING
14.6959	0.9800	0.9988	MISSING	MISSING	MISSING
14.6959	1.0000	1.0000	MISSING	MISSING	MISSING

PRES	MOLEFRAC	KVL2	BETA	MOLEFRAC	MOLEFRAC
		TOTAL	TOTAL	VAPOR	VAPOR
	CARBO-02	CARBO-02		METHA-01	CARBO-02

PRES PSIA	MOLEFRAC CARBO-02	KVL2 TOTAL CARBO-02	BETA TOTAL	MOLEFRAC VAPOR METHA-01	MOLEFRAC VAPOR CARBO-02
14.6959	0.0	MISSING	1.0000	1.0000	0.0
14.6959	2.0000-02	4.6954-05	0.9176	1.0000	1.1242-05
14.6959	4.0000-02	4.6953-05	0.8340	1.0000	1.1242-05
14.6959	6.0000-02	4.6952-05	0.7503	1.0000	1.1242-05
14.6959	8.0000-02	4.6951-05	0.6667	1.0000	1.1242-05
14.6959	0.1000	4.6949-05	0.5830	1.0000	1.1242-05
14.6959	0.1200	4.6955-05	0.4994	1.0000	1.1242-05
14.6959	0.1400	4.6955-05	0.4158	1.0000	1.1242-05
14.6959	0.1600	4.6955-05	0.3321	1.0000	1.1242-05
14.6959	0.1800	4.6955-05	0.2485	1.0000	1.1242-05
14.6959	0.2000	4.6955-05	0.1648	1.0000	1.1242-05
14.6959	0.2200	4.6955-05	8.1185-02	1.0000	1.1242-05
14.6959	0.2400	MISSING	1.0000	1.0000	1.1342-05
14.6959	0.2600	MISSING	1.0000	1.0000	1.5598-05
14.6959	0.2800	MISSING	1.0000	1.0000	2.2042-05
14.6959	0.3000	MISSING	1.0000	1.0000	3.1844-05
14.6959	0.3200	MISSING	1.0000	1.0000	4.6839-05
14.6959	0.3400	MISSING	1.0000	0.9999	6.9910-05
14.6959	0.3600	MISSING	1.0000	0.9999	1.0560-04
14.6959	0.3800	MISSING	1.0000	0.9998	1.6105-04

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES PSIA	MOLEFRAC CARBO-02	KVL2 TOTAL CARBO-02	BETA TOTAL	MOLEFRAC VAPOR METHA-01	MOLEFRAC VAPOR CARBO-02
14.6959	0.4000	MISSING	1.0000	0.9998	2.4758-04
14.6959	0.4200	MISSING	1.0000	0.9996	3.8303-04
14.6959	0.4400	MISSING	1.0000	0.9994	5.9564-04
14.6959	0.4600	MISSING	1.0000	0.9991	9.3001-04
14.6959	0.4800	MISSING	1.0000	0.9985	1.4566-03
14.6959	0.5000	MISSING	1.0000	0.9977	2.2866-03
14.6959	0.5200	MISSING	1.0000	0.9964	3.5944-03
14.6959	0.5400	MISSING	1.0000	0.9943	5.6525-03
14.6959	0.5600	MISSING	1.0000	0.9911	8.8814-03
14.6959	0.5800	MISSING	1.0000	0.9861	1.3920-02
14.6959	0.6000	MISSING	1.0000	0.9783	2.1715-02
14.6959	0.6200	MISSING	1.0000	0.9664	3.3608-02
14.6959	0.6400	MISSING	1.0000	0.9486	5.1387-02
14.6959	0.6600	MISSING	1.0000	0.9228	7.7199-02
14.6959	0.6800	MISSING	1.0000	0.8868	0.1132
14.6959	0.7000	MISSING	1.0000	0.8389	0.1611
14.6959	0.7200	MISSING	1.0000	0.7788	0.2212
14.6959	0.7400	MISSING	1.0000	0.7079	0.2921
14.6959	0.7600	MISSING	1.0000	0.6292	0.3708
14.6959	0.7800	MISSING	1.0000	0.5467	0.4533

14.6959	0.8000	MISSING	1.0000	0.4645	0.5355
14.6959	0.8200	MISSING	1.0000	0.3859	0.6141
14.6959	0.8400	MISSING	1.0000	0.3135	0.6865
14.6959	0.8600	MISSING	1.0000	0.2487	0.7513
14.6959	0.8800	MISSING	1.0000	0.1920	0.8080
14.6959	0.9000	MISSING	1.0000	0.1434	0.8566
14.6959	0.9200	MISSING	1.0000	0.1025	0.8975
14.6959	0.9400	MISSING	1.0000	6.8512-02	0.9315
14.6959	0.9600	MISSING	1.0000	4.0636-02	0.9594
14.6959	0.9800	MISSING	1.0000	1.8060-02	0.9819
14.6959	1.0000	MISSING	1.0000	0.0	1.0000

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES	MOLEFRAC CARBO-02	MOLEFRAC LIQUID 1 METHA-01	MOLEFRAC LIQUID 1 CARBO-02	MOLEFRAC LIQUID 2 METHA-01	MOLEFRAC LIQUID 2 CARBO-02
PSIA					
14.6959	0.0	1.0000	0.0	MISSING	MISSING
14.6959	2.0000-02	0.9997	2.9803-04	0.7606	0.2394
14.6959	4.0000-02	0.9997	2.9803-04	0.7606	0.2394
14.6959	6.0000-02	0.9997	2.9803-04	0.7606	0.2394
14.6959	8.0000-02	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.1000	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.1200	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.1400	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.1600	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.1800	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.2000	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.2200	0.9997	2.9803-04	0.7606	0.2394
14.6959	0.2400	0.7600	0.2400	MISSING	MISSING
14.6959	0.2600	0.7400	0.2600	MISSING	MISSING
14.6959	0.2800	0.7200	0.2800	MISSING	MISSING
14.6959	0.3000	0.7000	0.3000	MISSING	MISSING
14.6959	0.3200	0.6800	0.3200	MISSING	MISSING
14.6959	0.3400	0.6600	0.3400	MISSING	MISSING
14.6959	0.3600	0.6400	0.3600	MISSING	MISSING
14.6959	0.3800	0.6200	0.3800	MISSING	MISSING
14.6959	0.4000	0.6000	0.4000	MISSING	MISSING
14.6959	0.4200	0.5800	0.4200	MISSING	MISSING
14.6959	0.4400	0.5600	0.4400	MISSING	MISSING
14.6959	0.4600	0.5400	0.4600	MISSING	MISSING
14.6959	0.4800	0.5200	0.4800	MISSING	MISSING
14.6959	0.5000	0.5000	0.5000	MISSING	MISSING
14.6959	0.5200	0.4800	0.5200	MISSING	MISSING
14.6959	0.5400	0.4600	0.5400	MISSING	MISSING
14.6959	0.5600	0.4400	0.5600	MISSING	MISSING
14.6959	0.5800	0.4200	0.5800	MISSING	MISSING
14.6959	0.6000	0.4000	0.6000	MISSING	MISSING
14.6959	0.6200	0.3800	0.6200	MISSING	MISSING

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 !    14.6959 !     0.6400 !     0.3600 !     0.6400 !    MISSING !    MISSING !
 !    14.6959 !     0.6600 !     0.3400 !     0.6600 !    MISSING !    MISSING !
 !    14.6959 !     0.6800 !     0.3200 !     0.6800 !    MISSING !    MISSING !
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                          PHYSICAL PROPERTY TABLES SECTION

 FLASH CURVE TABLE:  BINRY-1 (CONTINUED)

 ----------------------------------------------------------------------------------
 !  PRES      !  MOLEFRAC  !  MOLEFRAC  !  MOLEFRAC  !  MOLEFRAC  !  MOLEFRAC  !
 !            !            !  LIQUID 1  !  LIQUID 1  !  LIQUID 2  !  LIQUID 2  !
 !            !  CARBO-02  !  METHA-01  !  CARBO-02  !  METHA-01  !  CARBO-02  !
 !            !            !            !            !            !            !
 !  PSIA      !            !            !            !            !            !
 !            !            !            !            !            !            !
 !============!============!============!============!============!============!
 !    14.6959 !     0.7000 !     0.3000 !     0.7000 !    MISSING !    MISSING !
 !    14.6959 !     0.7200 !     0.2800 !     0.7200 !    MISSING !    MISSING !
 !    14.6959 !     0.7400 !     0.2600 !     0.7400 !    MISSING !    MISSING !
 !    14.6959 !     0.7600 !     0.2400 !     0.7600 !    MISSING !    MISSING !
 !    14.6959 !     0.7800 !     0.2200 !     0.7800 !    MISSING !    MISSING !
 !------------+------------+------------+------------+------------+------------!
 !    14.6959 !     0.8000 !     0.2000 !     0.8000 !    MISSING !    MISSING !
 !    14.6959 !     0.8200 !     0.1800 !     0.8200 !    MISSING !    MISSING !
 !    14.6959 !     0.8400 !     0.1600 !     0.8400 !    MISSING !    MISSING !
 !    14.6959 !     0.8600 !     0.1400 !     0.8600 !    MISSING !    MISSING !
 !    14.6959 !     0.8800 !     0.1200 !     0.8800 !    MISSING !    MISSING !
 !------------+------------+------------+------------+------------+------------!
 !    14.6959 !     0.9000 !     0.1000 !     0.9000 !    MISSING !    MISSING !
 !    14.6959 !     0.9200 !  8.0000-02 !     0.9200 !    MISSING !    MISSING !
 !    14.6959 !     0.9400 !  6.0000-02 !     0.9400 !    MISSING !    MISSING !
 !    14.6959 !     0.9600 !  4.0000-02 !     0.9600 !    MISSING !    MISSING !
 !    14.6959 !     0.9800 !  2.0000-02 !     0.9800 !    MISSING !    MISSING !
 !------------+------------+------------+------------+------------+------------!
 !    14.6959 !     1.0000 !     0.0    !     1.0000 !    MISSING !    MISSING !
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                              PROBLEM STATUS SECTION

 BLOCK STATUS
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 ***************************************************************************
 *                                                                         *
 * Calculations were completed normally                                    *
 *                                                                         *
 * All Unit Operation blocks were completed normally                       *
 *                                                                         *
 * All Transfer blocks were completed normally                             *
 *                                                                         *
 * Flash errors occurred in Transfer blocks                                *
 * for the following streams:                                              *
 *   MIDALK2                                                               *
 *                                                                         *
 * All Convergence blocks were completed normally                          *
 *                                                                         *
 * All Property Tables were completed normally                             *
 *                                                                         *
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