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Renewable Ammonia

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Abstract

Ammonia is one of the most widely used chemicals that is commercially produced today given the wide need for fertilizer to sustain the world's ever-growing populations. Given the high world demand for ammonia, which increases every day, one can see how beneficial to the environment that a zero emission large-scale ammonia plant would be. Through the use of energy from Norwegian wind farms, which produce an excess of energy during off-peak hours, our plant design seeks to turn this wasted energy into useful ammonia products at a production rate of 67.2 kmol/hr.

The design of this ammonia synthesis plant can be split conceptually into two distinct halves. The first is the refinement of the hydrogen and nitrogen that are required for the Haber-Bosch synthesis from the raw inputs of air and water. This is done through the usage of solid oxide electrolytic cells which electrolyze the water into constituent hydrogen and oxygen atoms and separate the oxygen out of the air. The second half of the plant design is a typical Haber-Bosch ammonia synthesis that many plants today are utilizing. This section consists mainly of a reaction vessel at the correct operating conditions for the ammonia synthesis reaction to occur, and a series of separators that recoup the liquid ammonia product at the right conditions for storage while recycling the gaseous hydrogen and nitrogen reactants.

While this plant design provides a layout to accomplish the task of producing ammonia in an environmentally friendly way, it is less friendly to the wallet of the plant owner. Selling the ammonia product at current market rates of $853/ton, it would take roughly 15 years for the plant to overcome the capital investment of the venture and become a monetarily net positive design. Current utility prices are projected to cost the plant over $1.7 million dollars per year, which is another significant consideration why it takes such a large amount of time for the plant to become profitable.

It is our hope that ongoing refinement of solid oxide electrolytic units will enable their purchase at cheaper rates, and that as the environment worsens, a higher premium will be placed on chemical products that have been sourced renewably, both factors that could easily make this plant design a more viable option in the future than it currently is today.

Disciplines

Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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21 April 2020

Dear Mr. Bruce Vrana, Mr. Leonard Fabiano, and Dr. Raymond Gorte,

Please find attached our final report for CBE 459: Senior Design. Our project, titled "Renewable Ammonia", was proposed by two of our group members, James Kwon and Dakota Wallach. This project design focuses on the utilization of excess wind energy produced in Norway to produce liquid ammonia, creating a useful chemical product with no carbon footprint.

In the body of the report you will find our preliminary design for this plant, including a full economic analysis and the projected future feasibility of this design. The size of this ammonia production is on the smaller scale of a full-size facility, producing 46 MT/day of liquid ammonia. The cost associated with construction of this plant is comparatively large, due to the high cost of the solid oxide electrolytic cells (SOECs) that are utilized. The calculated net present value (NPV) of this plant is USD -22M, and the return on investment (ROI) is -0.68%.

Based on the findings of our analysis, we found that it would require operation of the plant for a large number of years before plant operation would become profitable. A number of external considerations, such as SOECs becoming considerably cheaper over time, the price of green ammonia increasing, or an increased carbon tax on plants that are not operating renewably could shorten this time before profitability is reached. Unfortunately, as for now it appears that operation is not profitable enough to be pursued at this time, and we recommend that any interested parties carefully consider the following report before making a final decision on construction of this plant.

Sincerely,

Kolbein Finsnes

James Kwon

Dakota Wallach

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1. Abstract

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While this plant design provides a layout to accomplish the task of producing ammonia in an environmentally friendly way, it is less friendly to the wallet of the plant owner. Selling the ammonia product at current market rates of $853/ton, it would take roughly 15 years for the plant to overcome the capital investment of the venture and become a monetarily net positive design. Current utility prices are projected to cost the plant over $1.7 million dollars per year, which is

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2. Introduction

2.1 Project Background

The Haber Bosch process (1910) is a fundamental chemical process that has fueled both economic and population growth. The invention brought about the mass production of ammonia, and both Haber and Bosch were awarded the Nobel Prize in Chemistry in 1918 and 1931 respectively. The process was first commercialized in 1913, proving instrumental to the growth of agricultural yields and more broadly sustenance of the human population. The inputs to the Haber Bosch processes are simple since it uses gaseous hydrogen and nitrogen reacted at high pressures and moderately high temperatures to produce gaseous ammonia which can subsequently then be cooled and liquefied. Nitrogen comprises 79% of the atmosphere by volume, and is generally obtained from air by separating oxygen. This is accomplished through a number of different air separation processes such as fractional distillation and pressure swing adsorption among others. Hydrogen, however, does not occur naturally and must be synthesized from some other source. Currently, most of the world's Hydrogen is synthesized using steam reforming, a process that converts methane (sourced from natural gas) into hydrogen and carbon dioxide.[1] However, one of the major drawbacks to this process is that it depends on fossil fuels that are not only unsustainable but harmful for the environment.

In recent years, there has been a large movement both in and outside of the scientific community to shift away from the use of fossil fuels. Consequently, this shift is not met without problems since major renewable energy sources continue to face issues of volatility, cost, and

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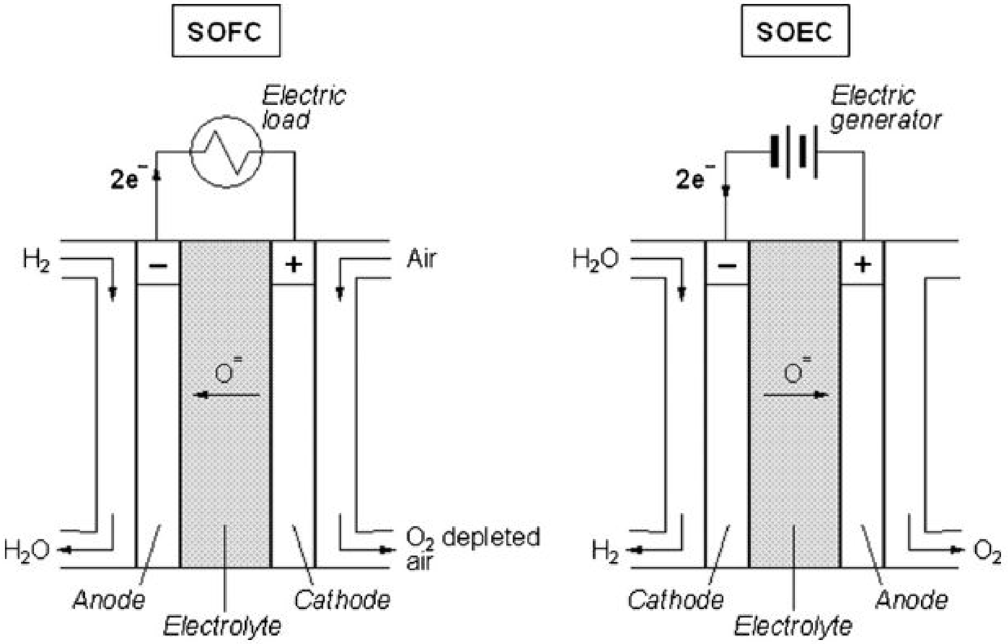
[1] Holladay, J.D., Hu, J., King, D.L., Wang, Y. (2009)

implementation. For example, renewable sources of energy such as wind or solar are often highly unreliable, with energy generation directly linked to uncontrollable factors such as wind speed, or daily hours of sunshine. As a result, an excess of energy is produced at times; at other times, there is a lack of electricity available. Excess energy is typically wasted or sold to other locations and can be a problem for energy producers. Rather than selling this excess, many firms have begun exploring ways to better maximize its utility by using the energy to drive processes such as producing hydrogen gas through the electrolysis of water.

A significant technological innovation that our process utilizes is in the method in which it produces hydrogen. Compared to the most popular form of hydrogen production (steam reformation) utilization of the solid oxide electrolyzer eliminates carbon emissions. Typically, this sort of system is run as a fuel cell where fuel is consumed in order to produce energy. Fuel in a gaseous form is run on the anode side where molecules will react with the yttria stabilized zirconia (YSZ) based Ni catalyst and oxygen ions from an oxygen input in the cathode migrate to the other side producing water and electricity. Typical materials include nickel mixed with Yttria Stabilized Zirconia (Ni-YSZ) for the anode and lanthanum strontium manganate (LSM) for the cathode. However, in our system, the cell is essentially run in reverse taking electricity as an input to split water molecules. Water in the form of steam is run on the cathode side where it is electrolyzed to H_2 and O^{2-} ions. These O^{2-} ions travel across the electrolyte and recombine on the anode side to produce oxygen. A diagram of this process versus standard fuel cells can be seen in the figure below.

Figure 2.1a: Visual depiction of how a solid oxide fuel cell (SOFC) and a solid oxide electrolyzer (SOEC) function.[2]



In addition, the system is able to achieve nitrogen separation with the oxygen as the potential at which the oxygen molecules react with the electrodes occur at a value close to 0V. The O_2 pressure difference between the two electrodes serves as a driving force for the separation of the oxygen from the nitrogen as well. Both electrolyzers and fuel cells are fabricated as smaller cells and combined to form giant stacks to permit larger amounts to be processed.

Following the generation of hydrogen and separation of nitrogen, these materials will be put into the Haber Bosch process. The initial feed to the ammonia synthesis reaction vessel is a mix of nitrogen and hydrogen, along with trace amounts of argon. The reactants are fed into the vessel at relatively high temperatures, slightly above 200 degrees Celsius, and at an incredibly

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[2] Iora, P., Chiesa, P. (2009)

high pressure of over 80 atmospheres of pressure. The reaction by which ammonia is synthesized is given below as *Equation 2.1a.*

Equation 2.1a: Reaction of Hydrogen and Nitrogen to Form Ammonia

$$3H_2 + N_2 \leftrightharpoons 2NH_3 \;\; \Delta H = -91.8\, kJ/mol$$

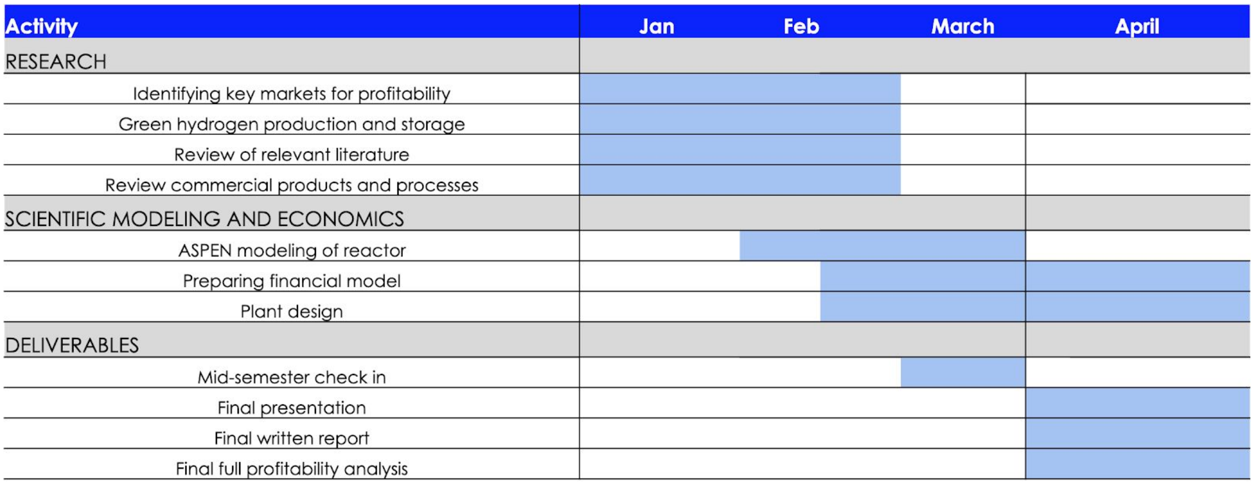
As one may notice, this reaction is immensely exothermic, meaning that a large amount of heat energy is produced as a result of this reaction proceeding. This also explains why the reaction requires such extreme conditions in order to make the reaction proceed. In order to facilitate this reaction, an iron catalyst is added, which is usually made of magnetite or similar ore. In this process, an iron catalyst doped with sodium has been chosen, as this catalyst is sufficiently efficient for the needs of our process at a price point that is more reasonable than other catalysts made of precious minerals. The addition of a high surface area iron catalyst creates a surface to which the hydrogen and nitrogen can adsorb strongly to, which facilitates the slowest step of this reaction, the splitting of the diatomic nitrogen into singleton components. The largest concern regarding the catalyst is that care must be taken to ensure that no oxygen is allowed to enter the vessel where the catalyst is used. Oxygen reacts strongly with iron in order to form metal oxides, which effectively poisons the catalyst and renders it useless. In order to avoid this, precautions are taken to ensure that the air entering the process has been sufficiently separated into oxygen and nitrogen, with the oxygen being vented out and sold. It is important to note that it is possible to regenerate the iron catalyst under some circumstances, but would require shutting down plant operations, which comes at a significant cost.

2.2 Project Proposal

The goal of this project was to design an ammonia plant that would utilize excess wind energy to drive electrolyzers which would produce the necessary inputs to the Haber Bosch process. Electrolysis of steam would form hydrogen while the nitrogen from the air would be separated through the electrolyzer as well. A solid oxide electrolyzer (SOEC) was chosen due its ability to utilize thermal and electrical processes to increase the efficiency of the overall process. One thing to note is that the scale to which we plan to use our SOECs currently do not exist but are expected to reach those sizes in the foreseeable future. All costs and various calculations were taken with values available as of today. The Haber Bosch process is typically a very energy and carbon intensive process due to the production of its feed streams but utilization of electrolysis largely eliminates both of these issues. The plant was designed with the goal of being as environmentally friendly as possible and carbon neutral. Extensive profitability and market analyses were conducted to determine necessary pricing measures for this process to become economically viable.

2.3 Project Timeline

Figure 2.3a: Graphical Depiction of Project Timeline



Activity	Jan	Feb	March	April
RESEARCH				
Identifying key markets for profitability	▨	▨		
Green hydrogen production and storage	▨	▨		
Review of relevant literature	▨	▨		
Review commercial products and processes	▨	▨		
SCIENTIFIC MODELING AND ECONOMICS				
ASPEN modeling of reactor		▨	▨	
Preparing financial model		▨	▨	▨
Plant design		▨	▨	▨
DELIVERABLES				
Mid-semester check in			▨	
Final presentation				▨
Final written report				▨
Final full profitability analysis				▨

Our project timeline can be seen in the figure depicted above. The bulk of our research and preparation took place in January and February where a plan for producing such hydrogen and the information relevant to the Haber Bosch process was determined. During February and March, the majority of the modelling of the entire process was initiated as the specific variable of plant operation and its various components were determined. The work in April mostly consisted of profitability analysis, the preparation of the final presentation, and the synthesis of the relevant findings into a final written report.

3. Market and Competitive Assessment

3.1 Uses

Ammonia (NH3) is a colorless gas at standard temperature and pressure. In 2019, more than 80% of ammonia produced was used by the agriculture industry as fertilizer.[3] This represents the largest industry use of ammonia by both mass and revenue.

Instead of only relying on farming techniques such as crop rotation and allowing land to lie fallow, fertilizer provides an alternative that drastically increases efficiency in farming. When crops grow in a field, nitrogen in the soil is depleted. Some plants, such as legumes, are nitrogen fixers, whose roots have bacteria that increase the amount of nitrogen present in the soil. Although nitrogen is highly present in the atmosphere (comprises 79% of air), it cannot be used in its elemental form. Ammonia as fertilizer has decreased the need for nitrogen fixers, and has drastically increased the efficiency of farms.

Ammonia can either be directly applied to soil or converted to a salt (such as ammonium nitrate) through a straightforward crystallization process and then applied. This report covers only the production of ammonia from raw materials. Although use of ammonia varies by farm and crop, a safe estimate is that 1 ton of anhydrous ammonia covers about 9.6 acres of farmland for standard application of fertilizers. Alternatively, 104kg of anhydrous ammonia is necessary per acre, per year.[4]

Ammonia is also used in cleaning products such as Windex and other glass cleaners.

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[3] Mordor Intelligence, Ammonia Market (2020), Retrieved April 9th, 2020 from https://www.mordorintelligence.com/industry-reports/ammonia-market

[4] Schnitkey, Gary, “Nitrogen Fertilizer Prices and Costs Lower for 2018”, November 2017, Accessed April 10th, 2020 from https://farmdocdaily.illinois.edu/2017/11/nitrogen-fertilizer-prices-and-costs-lower-for-2018.html

3.2 Market Overview

In 2020, the global ammonia market size is projected to be worth roughly USD 72.8 billion, with a CAGR of ~1.1%.[5] The market is highly commodified and low growth (global GDP growth is projected to be ~3%). Nearly all hydrogen is currently sourced from natural gas via steam reforming. North America and Europe are classified as medium growth areas for demand of ammonia, for this industry.[6] High growth regions include China, Russia, Brazil and sub-Saharan Africa. (Mordor Intelligence)[7]. More than half of ammonia is consumed in Asia. This market share is expected to grow, as regions in Asia have high population growth rates and strong agricultural industries that rely on fertilizers.

3.3 Competitors

Due to the massive size of the ammonia market and uniformity of ammonia, the market is highly fragmented, with many players and high levels of competition. This is typical of highly commoditized markets, business to business markets. Margins are generally very small, and supply chains are fully integrated to cut costs. The world's largest ammonia producer is Norway based Yara. Other major players include BASF (the "firm that tasked Carl Bosch with the commercialization of Fritz Haber's ammonia synthesis process in 1910" - AmmoniaEnergy.org), CF Industries, Qatar Fertilizer Company, SABIC and EuroChem. (Mordor Intelligence).

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[5] MarketWatch, Ammonia Market 2020, March, 2020, Retrieved April 10th 2020, from https://www.marketwatch.com/press-release/ammonia-market-size--industry-growth-analysis-2020-regional-outlook-trends-opportunity-revenue-share-forecasts-by-2025-2020-03-02

[6] Mordor Intelligence, Ammonia Market (2020), Retrieved April 9th, 2020 from https://www.mordorintelligence.com/industry-reports/ammonia-market

[7] Ibid.

The above firms produce ammonia from fossil fuels, which produce greenhouse emissions and rely on the oil and gas industry. There are currently very few firms operating in the green ammonia space, and there are no wind-power green ammonia plants currently built. Many large ammonia players (such as Yara) are attempting to innovate and move into green ammonia should costs lessen and commercial viability increase. Even though ammonia produced from fossil fuels and wind farms is identical, if carbon tax credits were to make green ammonia more viable, it could disrupt the ammonia industry and become a space for mass innovation.

4. Preliminary Process Synthesis

4.1 Hydrogen Generation

While there are many different methods for producing hydrogen, hydrocarbon reforming is responsible for producing the vast majority of hydrogen consumed today. Hydrocarbon reforming can be performed by steam reforming, partial oxidation, or a combination of the two, autothermal reforming. These processes are essentially similar but still contain enough nuances to warrant different For large-scale processes, steam reforming is the most practical since it does not require oxygen, has the lowest process temperatures and the best H_2/CO ratio for H_2 production. These advantages are partially offset in regards to the process as a whole since the air emissions are the highest of the three.[1] The goal of the project was to produce hydrogen utilizing a greener method to produce the feedstock for the Haber Bosch process. This led to water electrolysis since this is the next most efficient method for producing hydrogen.

There are a number of different ways to accomplish water electrolysis, with commercialization proceeding on electrolyzers based on alkaline, polymer membrane, and solid oxide membranes. Solid oxide electrolyzers were chosen due to their high efficiencies, associated in part with their high operating temperatures. High temperatures greatly reduce electrode overpotentials and allow overall system efficiencies by using the waste heat to assist in the overall production of hydrogen. For modelling purposes, we use solid oxide fuel cells (SOFC) as a guideline as they are essentially SOECs run in reverse.

4.2 Nitrogen Separation

The nitrogen that is to be used in the process will be sourced from air. However, since nitrogen is not the only component present in air, extra steps must be taken to remove the other components (mainly oxygen) from the air. There are a number of different methods that are used in industry to separate air: fractional distillation, pressure swing adsorption, and vacuum swing adsorption. Out of these methods, fractional distillation in the form of cryogenic air separation is the most common. This process requires a tight integration of heat exchangers and separation columns to obtain an overall good efficiency for the process. One of the advantages of utilizing the SOECs is that the process of removing oxygen from the air comes at close to no energic cost as the voltage at which this occurs is roughly around 0V. In our process, oxygen removal is accomplished partly due to the reaction between hydrogen and oxygen which generates water and the removal of the remaining oxygen across the electrolyzer. This eliminates the need for the purchase of the air separation and is integrated directly as a part of our process.

4.3 Utilization of Excess Wind Energy

To power the solid oxide electrolyzers, the standard approaches of utilizing traditional electricity sources were cast aside in favor of utilizing excess wind energy. Due to the intermittent nature of wind and solar energy, electricity generation varies depending on the position of the sun or the amount of wind that is blowing at any given moment. This leads to discrepancies in generation since there are times of the day (particularly at night when electricity usage is low) when the electricity demand is less than the electricity generated by these sources. The excess electricity is typically sold off to other countries or stored in some form. As an alternative, it was decided that renewable excess energy should be used as the energy source for our electrolyzers. However, this by no means suggests that our process will be shut off when there is no wind available, the discrepancies will be supplied by electricity that is purchased and available on demand. Wind energy in particular was chosen as the source of energy as wind farms are typically located near bodies of water serving as a perfect location to source our water input to the process as well.

5. Assembly of Database

5.1 Cost of Chemicals

The raw materials utilized in this design are water and air. There is not an associated purchase price with either of these starting reagents, as they can both be sourced free of cost. The cost associated with separating these raw materials into the desired hydrogen and nitrogen inputs into the Haber-Bosch process are contained in the costs of the unit modules and electricity. Other costs, including water to be used as steam or for cooling throughout the process, are taken from standard pricing guidelines and included in Section 16.

The product that will be sold is liquid ammonia that will be stored at low temperatures and lightly pressurized. The market price for our ammonia will be $500/ton, which is competitive in the current market. Considerations were made to theoretically include the price of ammonia sold per ton due to the fact that the ammonia produced by this process will be made exclusively using renewable energy, and, as such, could be worth the extra price to environmentally conscious purchasers. As of now, concerns over pricing our ammonia out of the market outweigh this potentially monetary benefit until it becomes clearer that there is enough demand for green ammonia to justify an increased price.

5.2 Catalyst Properties

Catalysts are frequently employed to increase the rate of reactions, typically by lowering some activation energy barrier without the catalyst being consumed in the process. For the Haber-Bosch reaction, a potassium-doped porous iron catalyst is the most common due to the significant increase in reaction rate, along with the cheaper price of iron compared to more expensive catalyst materials. For this reaction, the Haldor Topsoe KM 111 magnetite catalyst was chosen for its proven success and stability in ammonia synthesis processes. This catalyst works by providing a surface to which the hydrogen and nitrogen will both strongly adsorb to. The fact that the catalyst is porous is of note because the increase in surface area allows for more catalysis to occur on the surface, increasing the reaction rate significantly.

5.3 Chemical Properties

Material Safety Data Sheets (MSDS) for each of the components of this process can be found in *Appendix C.* Considerations based on the safety of the chemicals in this process were obtained from the MSDS's, and can be found in *Appendix C*. The property data for the components of our process can be found in **Table 5.3a** and **Table 5.3b** below.

Table 5.3a Properties of Chemicals in Process (at STP)

Chemical Name	Molar Mass (lb/lbmol)	Density (lb/ft^3)	Boiling Point (°F)	Heat Capacity (BTU/lb°F)
Water	18.02	62.43	212.0	1.001
Oxygen	15.99	0.08	-297.4	0.212
Hydrogen	2.02	0.01	-423.2	3.42
Nitrogen	32.00	0.07	-320.4	0.25
Argon	39.95	0.11	-302.5	0.12
Ammonia	17.02	0.044	-28.0	0.52

Table 5.3b Properties of Utilities in Process

Material	Inlet Temperature (°F)	Heat Capacity (BTU/lb°F)
Cooling Water	80	1.001
Chilled Water	45	1.001
Chilled Brine	0	1.001*

*In our simulation, chilled brine was approximated to have the heat capacity of water

5.4 Aspen Simulation Specifications

The overall design was simulated in ASPEN Plus V11. The SRK property method was used throughout the simulation except for the SOEC and autothermal reactions which occured in RSTOIC blocks which were manually input using calculations done in Excel and by hand.

The autothermal reaction was modelled in ASPEN using a mixer block to combine the streams and an RSTOIC block was used to show the extent of the reaction. The calculations regarding the amount of reactants formed and the temperature change that occurred was done by Excel using specific heats and enthalpy values at 800°C that were obtained from the NIST database.

The SOEC was modelled by taking the power and using a specified voltage and current to determine exactly how much hydrogen would be converted by the system. In ASPEN, these conversion values were input into an RSTOIC block and the molar flow rate of the reaction was used to convert the products. A SEP unit was used to split the stream into its two components because in a real system, the products of the reactions end up forming on the other side of the electrolyzer and never mixes with the cathode inputs to the process.

Coolers, heat exchangers, and condensers in the system were modelled using the HX block in ASPEN. Both the coolers and condenser had cold water running as the cooling fluid in the system. For the condenser however, since the process leads to two different phases being formed, an additional SEP unit was added to ensure that there was separation of the two phases.

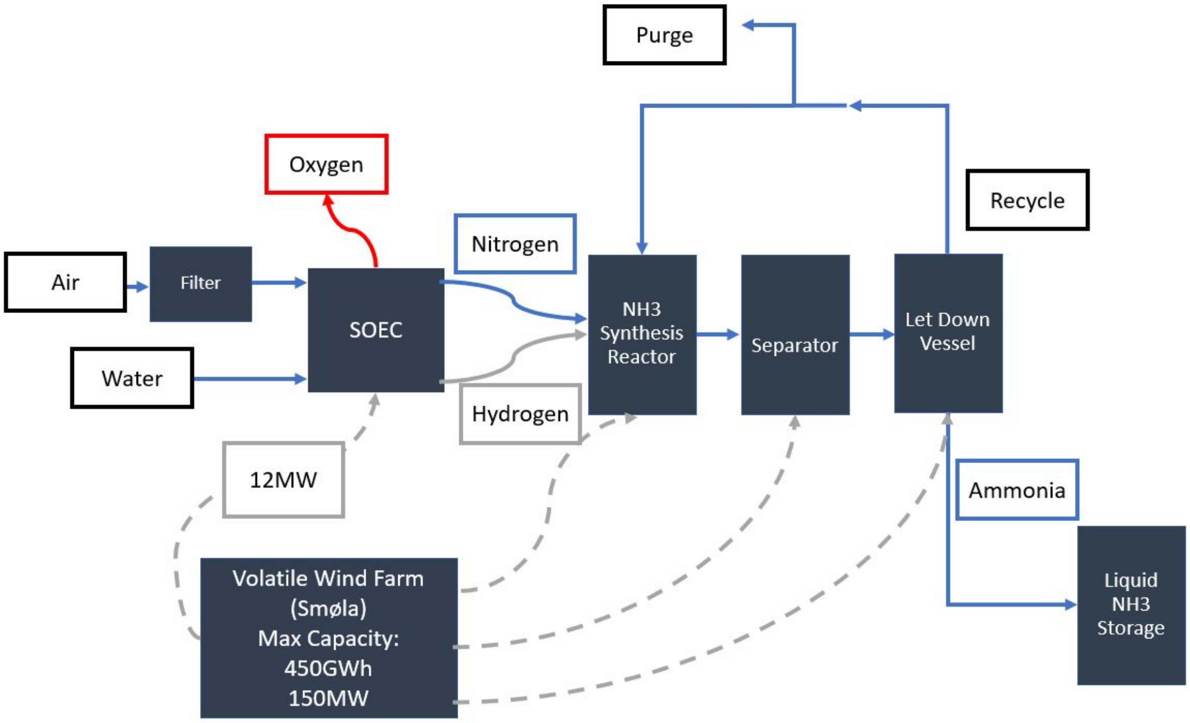
In the Haber Bosch process, the reaction vessel was modeled as an RSTOIC block as well with the reaction information input into the system to determine the conversion and the flow rates of the output. Both the primary separation vessel and the let-down vessel were modeled as SEP units.

6. Process Flow Diagram and Material Balances

6.1.1 Overall Simplified Process Flow Diagram

A simplified version of the overall process can be seen in **Figure 6.1.1** This diagram incorporates all of the major components of the process and contains the input and exit streams of the process as well.

Figure 6.1.1 Overall flow sheet which describes the major processes involved in ammonia synthesis, including reactants, intermediates, and ammonia product.



6.1.2 Overall Material Balance

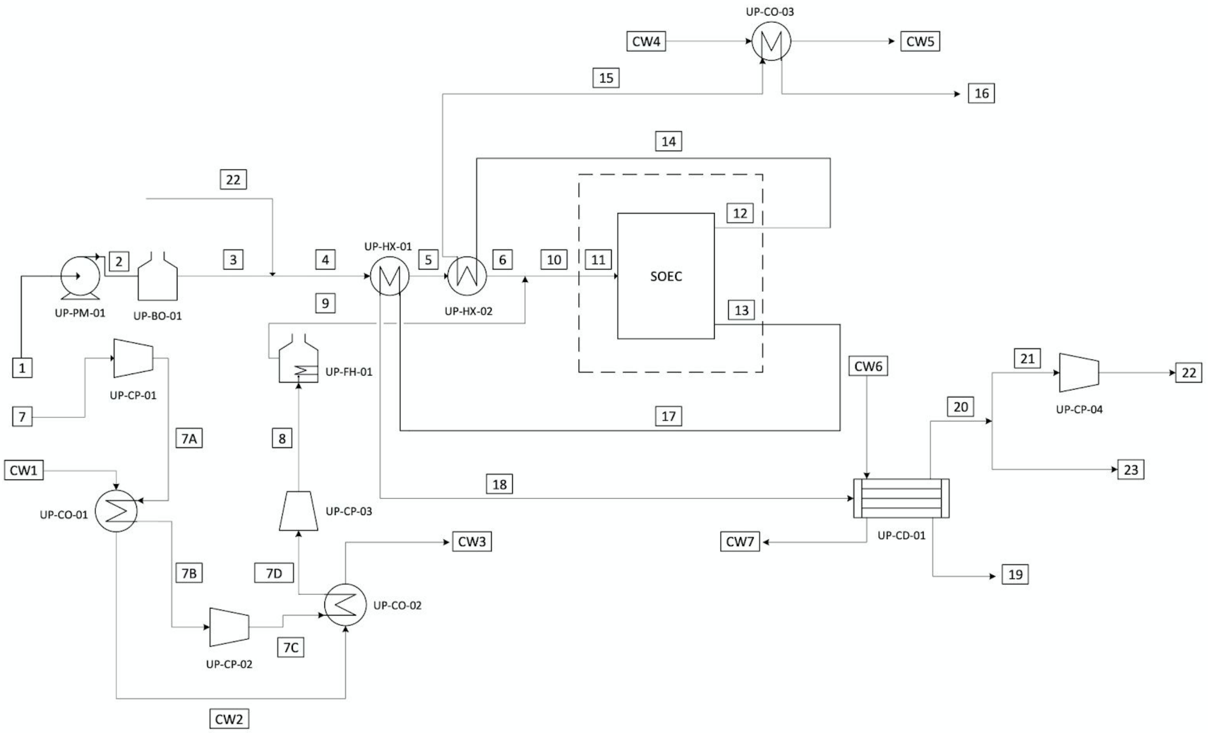
Table 6.1.2a Overall Material Balance Descriptions

Stream	Water In	N_2 In	O_2 In	Ar In	H_2 Out	N_2 Out	Ar Out	NH_3 Out	O_2 Out
Temp (°C)	25	25	25	25	20	20	20	20	35
Pressure (atm)	1	1	1	1	10.1	10.1	10.1	10.1	38.9
Mass Flow (kg/hr)	8858	1599	493	26	0.02	9.2	2.8	19448	2739
Mole flow (kmol/hr)	491.7	57.1	15.4	0.66	0.01	0.33	0.07	1144	84.4

6.2.1 Process Flow Diagram of the Solid Oxide Electrolytic Cell Processes

The overall process flow diagram for the generation of the inputs (hydrogen and nitrogen) to the Haber Bosch process is depicted in **Figure 6.2.1a**.

Figure 6.2.1a: Process flow diagram with all of the physical units involved in the process.



The process begins with water and air entering as streams 1 and 7 respectively. Both streams undergo a compression process to 40 bars and are heated then later mixed in the process. As this mixed temperature is moderately high, it undergoes the oxyhydrogen reaction and enters the SOEC system at 800°C. The remaining oxygen is separated out and the water is electrolyzed to hydrogen and oxygen. The stream entering the box with the dotted line will be split into 24 and enter 24 different SOEC stacks rated at 500kW. Streams 11 and 12 are the output of each of the 500kW SOEC units and combined to form streams 13 and 14. Effectively, the system will be run in parallel. Stream 14, which contains pure oxygen, will be cooled and sent for storage. Stream 17, which contains water, hydrogen, nitrogen, and argon will be condensed to eliminate the water and some of the gas will be used as inputs to the Haber Bosch process while the rest will be recycled in the process.

6.2.2 Material Balance of the Solid Oxide Electrolytic Cell Process

Table 6.2.2a summarizes the basic stream properties and material flow rates of all the streams pictured in **Figure 6.2.1a**

Table 6.2.2a: Summary of the streams properties and flow rates drawn in the PFD

Stream Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7A**
Temperature (°C)	25	26.2	420	379.9	590	610	25	197.9
Pressure (bar)	1	40	40	40	39.7	39.3	1	3.42
Mass Flow (kg/hr)	8858.1	8858.1	8858.1	9545.7	9545.7	9545.7	2118.7	2118.7
Molar Flow (kmol/hr)	491.7	491.7	491.7	563.1	563.1	563.1	73.2	73.2
Components (kmol/hr)								
H_2O	491.7	491.7	491.7	491.7	491.7	491.7	0	0
H_2	0	0	0	50.6	50.6	50.6	0	0
N_2	0	0	0	20.6	20.6	20.6	57.1	57.1
O_2	0	0	0	0	0	0	15.4	15.4
Ar	0	0	0	0.24	0.24	0.24	0.66	0.66

Stream Number	**7B**	**7C**	**7D**	**8**	**9**	**10**	**11**	**12**
Temperature (°C)	37.8	236.2	37.8	222.9	550	800	800	800
Pressure (bar)	3.1	11.7	11.4	40	40	39.3	39.3	39.3
Mass Flow (kg/hr)	2118.7	2118.7	2118.7	2118.7	2118.7	11664	486	114.1

Molar Flow (kmol/hr)	73.2	73.2	73.2	73.2	73.2	620.9	25.9	3.6
Components (kmol/hr)								
H_2O	0	0	0	0	0	522.5	21.8	0
H_2	0	0	0	0	0	19.8	0.8	0
N_2	57.1	57.1	57.1	57.1	57.1	77.7	3.2	0
O_2	15.4	15.4	15.4	15.4	15.4	0.0	0	3.6
Ar	0.66	0.66	0.66	0.66	0.66	0.90	0.04	0

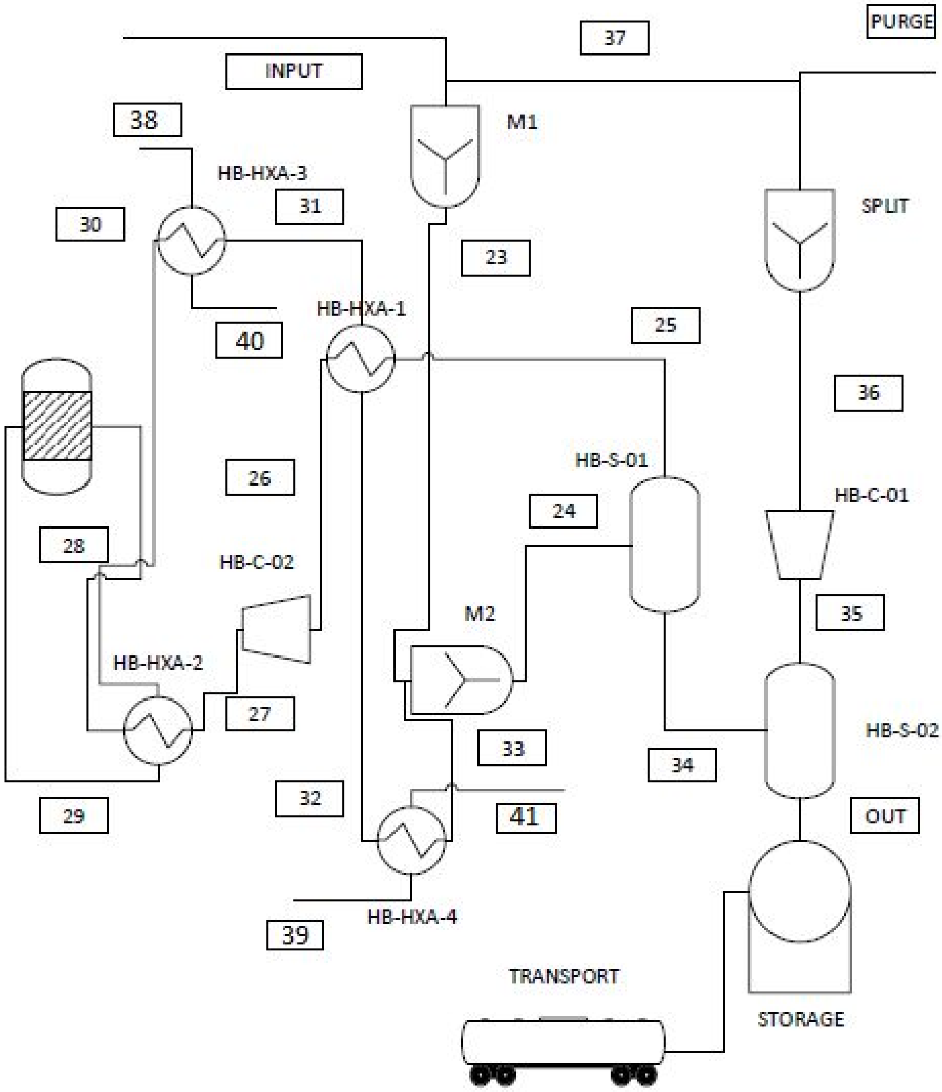
Stream Number	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Temperature (°C)	800	800	649.6	35	800	598.2	35	35
Pressure (bar)	39.3	39.3	39.0	38.9	39.3	39.0	38.9	38.9
Mass Flow (kg/hr)	371.9	2739.1	2739.1	2739.1	8925.4	8925.4	6330.6	2594.8
Molar Flow (kmol/hr)	25.9	85.6	85.6	85.6	620.9	620.9	351.3	269.5
Components (kmol/hr)								
H_2O	14.6	0	0	0	351.3	351.3	351.3	0
H_2	8.0	0	0	0	191.0	191.0	0	191.0
N_2	3.2	0	0	0	77.7	77.7	0	77.7
O_2	0	85.6	85.6	85.6	0	0	0	0
Ar	0.4	0	0	0	0.90	0.90	0	0

Stream Number	**21**	**22**	**23**
Temperature (°C)	35	38.4	35
Pressure (bar)	38.9	40	38.9

Mass Flow (kg/hr)	687.6	687.6	1907.2
Molar Flow (kmol/hr)	71.4	71.4	198.1
Components (kmol/hr)			
H_2O	0	0	0
H_2	50.6	50.6	140.4
N_2	20.6	20.6	57.0
O_2	0	0	0
Ar	0.24	0.24	0.66

6.3.1 Process Flow Diagram of the Ammonia Synthesis Process

Figure 6.3.1 Process flow diagram which describes the unit operations and streams that are involved in the Haber-Bosch portion of the overall plant design.



6.3.2 Material Balance of the Haber Bosch Process

Table 6.3.2a: Haber Bosch Material Balance Descriptions

Stream Number	**INPUT**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
Temperature (°C)	35	36.7	232.5	30	90	192.6	225	400
Pressure (bar)	39.6	39.6	35.2	39.6	39.3	81	81	81
Mass Flow (kg/hr)	1,907	1,944	20,480	19,300	19,300	19,300	19,300	19,300
Molar Flow (kmol/hr)	198.1	200.2	1548	1479	1479	1479	1479	1393
Components (kmol/hr)								
H_2O	0	0	0	0	0	0	0	0
H_2	140.4	140.5	641.7	641.7	641.7	641.7	641.7	513.2
N_2	57	57.2	326.7	326.7	326.7	326.7	326.7	283.6
NH_3	0	1.86	572.2	503.1	503.1	503.1	503.1	588.6
Ar	0.66	0.67	7.3	7.3	7.3	7.3	7.3	7.3

Table 6.3.2a: Haber Bosch Material Balance Descriptions

Stream Number	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
Temperature (°C)	368.1	364.6	303.8	256.1	30	20	170.8	170.8
Pressure (bar)	81	81	35.5	35.1	39.6	10.1	39.6	39.6
Mass Flow (kg/hr)	19,300	19,300	19,300	19,300	1,182	37.2	37.2	37.2
Molar Flow (kmol/hr)	1,393	1,393	1,393	1,393	69.4	2.2	2.2	2.2
Components (kmol/hr)								
H_2O	0	0	0	0	0	0	0	0

H_2	513.2	513.2	513.2	513.2	0.2	0.2	0.2	0.2
N_2	283.6	283.6	283.6	283.6	0.2	0.2	0.2	0.2
NH_3	588.6	588.6	588.6	588.6	69	1.9	1.9	1.9
Ar	7.3	7.3	7.3	7.3	0.1	0	0	0

Table 6.3.2a: Haber Bosch Material Balance Descriptions

Stream Number	**38**	**39**	**40**	**41**	**OUT**	**PURGE**
Temperature (°C)	7.2	7.2	32.2	32.2	20	171
Pressure (bar)	1	1	1	1	10.1	39.6
Mass Flow (kg/hr)	1754	23,010	1754	23,010	1,145	0.8
Molar Flow (kmol/hr)	97.4	1277	97.4	1277	67.2	.02
Components (kmol/hr)						
H_2O	97.4	1277	97.4	1277	0	0
H_2	0	0	0	0	.01	0.006
N_2	0	0	0	0	0.33	0.008
NH_3	0	0	0	0	1144	0.006
Ar	0	0	0	0	0.07	0.006

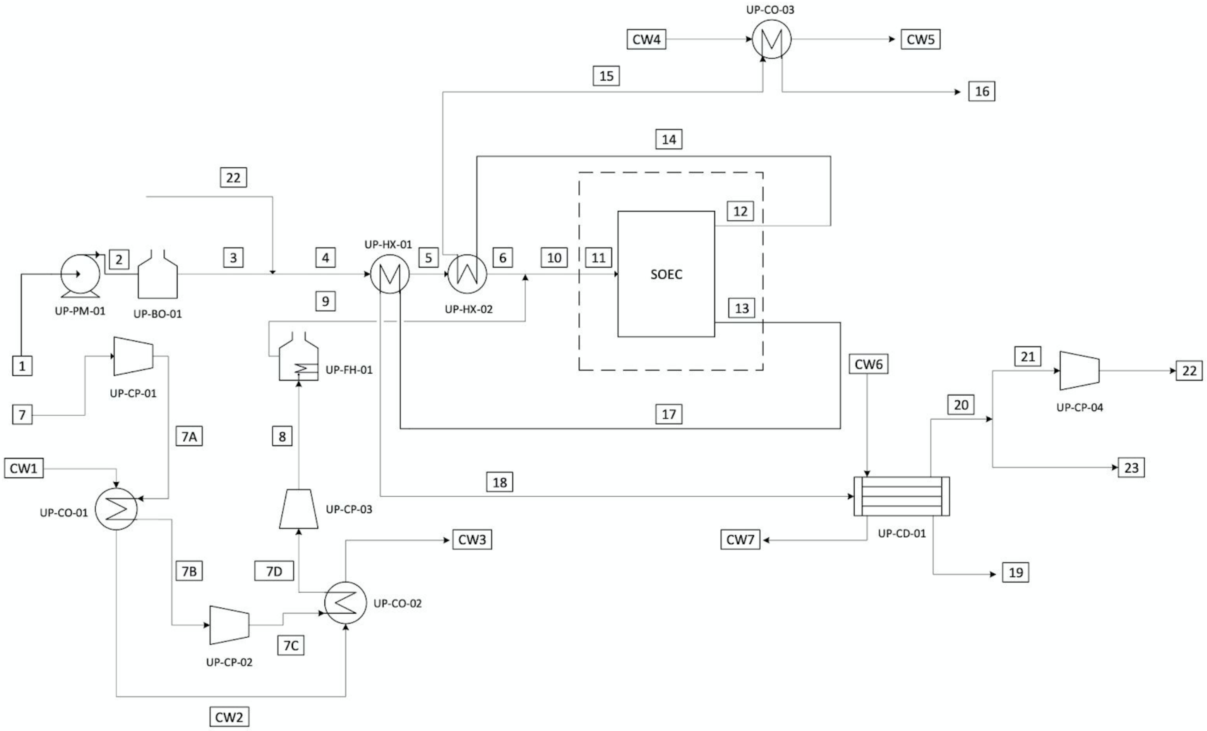
7. Process Descriptions

The overall process is broken down into two main sections: production of the reactants and the Haber Bosch process itself.

7.1.1 Feed Stream Sourcing and Preparation

Since the inputs to our process are simply air and water, we can source them directly from the environment. However, for the air, due to the presence of possible pollutants and solid particles present in the air, it will be run through a filtration system to avoid contamination and any possible issues to the system. The water does not necessarily need to go through such a process because the solids will fall out and instead remain in the boiler when the water is boiled. However, if clean water could be obtained that would be favorable as it would lower the frequency of required cleanings on the boilers. It will be assumed that the water has no solids. Both of the inputs will be heated and compressed prior to mixture with the H_2/N_2 mixture that is recycled from the process. Argon is present all throughout the process and accounted for in the calculations but will not be dealt with until the Haber Bosch process where it will be purged. **Figure 6.2.1a** is reprinted below for convenience.

Figure 6.2.1a: Process flow diagram with all of the physical units involved in the process.



7.1.2 Water Compression and Heating (UP-PM-01, UP-BO-01)

In order to produce hydrogen from water, the water must enter the SOEC system as compressed steam. To accomplish this, a pump with two stages (UP-PM-01) is used to first bring the input water at 25°C and 1bar to 40 bar. Following this process, the water is subsequently heated to 420°C by a boiler (UP-BO-01). This is in order to help achieve a reaction temperature that is able to support the reaction of hydrogen and oxygen in stream 6 and also ensures that the temperature at the end of the reaction will be at 800°C, the temperature at which our SOEC system is run. Prior to combination with the ar stream, the hydrogen + nitrogen is added from a recycle stream. This hydrogen + nitrogen stream is at a lower temperature (35°C) than the water stream and lowers the total stream temperature to about 380°C. The steam, hydrogen, and nitrogen stream is elevated to higher temperatures by a series of two heat exchangers as well prior to the addition of the air stream.

7.1.3 Air Filtration, Compression, and Heating (UP-CP-01, UP-CO-01, UP-CP-02, UP-CO-02, UP-CP-03, UP-FH-01)

The input air sourced from the environment is assumed to enter the process having passed a filter used to remove undesirable particles at 25°C and 1 bar similar to the water. It undergoes a compression process as well but is slightly different to the water as the air requires the use of compressors rather than a pump due to its physical state. After the first compressor (UP-CP-01), the air achieves a pressure of 3.42 bar. However, the temperature of the stream increases to 197.91°C. As this is undesirable due to more work needing to be exerted by the compressor to achieve the same pressure, before entry into the second compressor (UP-CP-02), the air stream enters a cooler (UP-CO-01) which decreases the temperature of the system to 37.8°C. This stream is then fed again into another compressor (UP-CP-02) which raises the pressure and temperature of the stream to 11.7 bar and 236.22°C. This stream enters another cooler (UP-CO-02) which cools the stream to 37.8°C and enters the final compressor (UP-CP-03) which brings the stream up to 40bar. Cooling water at 80°F or 26.67°C was used as the cold streams for the coolers. After this step however, the stream is not cooled again as having a higher temperature is desirable in our process due to the combination with the water stream needing to achieve temperatures higher than the oxyhydrogen reaction temperature which can be achieved at temperatures as low as 560°C.[8] The stream exits the final compressor at 40 bar and 222.91°C.

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[8] Airliquide Hydrogen Safety Data Sheet

This is not hot enough to maintain a temperature hot enough where the oxyhydrogen reaction or ignition of hydrogen will take place upon combination with the steam, hydrogen, and nitrogen stream. It will undergo an additional heating process in a fired heater (UP-FH-01) which heats the stream up to 550°C and afterwards gets combined with the other input stream.

7.1.4 Heat Exchangers (UP-HX-01, UP-HX-02)

Stream 4 passes through a series of heat exchangers in order to elevate the temperature of 610°C. This temperature is chosen so that when the air gets added to the process the change does not lower the temperature to a point where the oxyhydrogen reaction does not occur. Both heat exchangers utilize the products of the SOEC to heat up the reactants as they both leave the SOEC system at 800°C. These hot streams are both used to heat up the inputs and have a minimum approach temperature greater than 10°C. This was chosen to ensure that the driving force was large enough. A drop of 5 psi was assumed for each exit stream.

7.1.5 Oxyhydrogen Reaction

Hydrogen and oxygen will react when stream 6 combines with stream 9. The main components of this reaction involve oxygen from the air and the hydrogen from the recycle to undergo this process. Excess water is kept to ensure that the temperature increase caused by this reaction is not excessive as there are lower limits to which this reaction can get started. The water in addition is later hydrolyzed in the process to form more hydrogen and O_2 although from a strict stoichiometric perspective this seems intuitive but this process is crucial to the overall system for a number of reasons. First, it is an excellent way to separate the oxygen from the air so that we may obtain nitrogen as a part of the process. This allows all the energy of the solid oxide electrolyzers to be utilized in producing hydrogen. In addition, it reduces heating costs of the system as more energy does not need to be spent to increase the temperature of the inputs of the SOEC to the operating temperature of the electrolyzer and the electrolyzer itself. Lastly, this process is advantageous as the oxygen cannot be exposed to the cathode side as it would degrade cell and thereby incur greater costs, Considering that the SOEC system to date is the most expensive units of the system, it is prudent to ensure the longevity of these systems at over others. For the process, it is assumed that all the oxygen that is input from the air into the process is reacted in this manner.

7.1.6 Solid Oxide Electrolyzer Network (SOEC)

Each stack in our system was given a rating of 500kW in order to determine an appropriate price and current which would allow us to calculate the conversion of water to hydrogen within our system. 24 units each rated at 500kW would be put in parallel to process the hydrogen in the system. Taken at 1.285V, the thermoneutral voltage for the electrolysis of water at 800°C, this would lead to a current of 9.231*10^6 amps to be run throughout the whole system.[9] Given that the current is used to electrolyze water, this would produce 171.2kmol H_2/hr. Due to the system operating at the thermoneutral voltage, it will not experience a change in temperatures in the output and allows us to utilize the high temperature to heat up our inputs in UP-HX-01 and UP-HX-02. The calculations for the production of kmols H_2/hr can be found in

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[9] High temperature electrolysis cell. Retrieved April 1, 2020 from http://www.helmeth.eu/index.php/technologies/high-temperature-electrolysis-cell-soec

Appendix A.1. The O_2 partial pressure difference between the two electrodes will help any possible unreacted oxygen to be separated from the input stream.

7.1.7 Oxygen Cooler (UP-CO-03)

One of the primary products of the SOEC is in the form of oxygen gas created from the electrolysis of water to produce hydrogen. The oxygen product is completely pure given that no air is run on the anode side of the SOEC to allow the oxygen to flow out of the electrolyte. This also allows there to be a greater O_2 partial pressure difference to exist between the electrodes of the fuel cell system. As a result of the process, 85.6 kmol O_2/hr is produced and this stream leaves the anode side of the SOEC to be used as the hot fluid for UP-HX-02. The oxygen product leaves the heat exchanger at 649.6°C and enters a cooler that brings the temperature of the stream down to 35°C to permit the easier/safer storage of oxygen. The exact specifications of exactly how the oxygen was stored and sold were beyond the scope of the project. Cooling water at 26.7°C was used as the cold stream to this process.

7.1.8 SOEC Product Condenser (UP-CD-01)

The gaseous stream containing hydrogen, nitrogen, and the remaining water leaves the cathode side of the electrolyzer and enters a heat exchanger (UP-HX-01) to heat up the inputs entering the SOEC. After this process, this stream is sent to a condenser for the removal of the water. It is much easier to do so when it exists in liquid form. By decreasing the temperature significantly, during this operation, the hydrogen and nitrogen will remain as a gas while the water condenses and exits the process as a liquid. The temperature that the streams leave the condenser is 35°C as it is undesirable to leave hydrogen at high temperatures for safety reasons. Cooling water was once again used as the cold stream to the unit entering at 26.67°C. More cold water was added than necessary to allow the exit cooling water to remain below 30°C which preserves a reasonable driving force for the heat to be transferred across the two streams.

7.1.9 Recycle Stream Compressor (UP-CP-04)

After condensing the water and eliminating it from the system, the gaseous stream consisting of primarily hydrogen and nitrogen is split with roughly 75% of the stream entering the next step of the process. The remaining 25% of the gas is sent to a compressor which raises the pressure back up to 40 bar for re-entry into the production of hydrogen and serves as the hydrogen component for the oxyhydrogen reaction.

7.2.1 Ammonia Synthesis Reaction Vessel (HB-RXN)

For the given catalyst, the mass of catalyst required was calculated as a function of the GHSV and reactor size. The mass of catalyst required was found to be 316 kg at a price of \$20/kg of catalyst. The total amount of capital dedicated to purchasing the catalyst is \$20,000 to account for the 6-month cycle that the catalyst is functional for over the duration of the plant life.

It is further worth noting that the reaction has a relatively low single-pass conversion, only nearing 15-20% per pass through the reactor. However, repeated cycles through the entirety of the process is easily achieved and brings the total reaction rate close to completion. Through this recycle stream, a large amount of otherwise unreacted reagents are converted into the useful ammonia product.

The physical design of the reactor is that of a very tall tower with a relatively low pressure drop. There will be three catalyst beds, where the mixture will be allowed to react in separate layers to increase process efficiency. This gaseous ammonia product will be constantly removed to increase the reaction rate of the product in accordance with Le Chatlier's principle. This product mix will then be cooled slightly using chilled water and the incoming gas to the reactor. From this point, the gas will be sent to the separation column to recover the product.

7.2.2 Separation Column (HB-S-01)

The separation column, labeled HB-S-01 in **Figure 6.3.1a**, is a column that serves to separate the liquid ammonia product to be stored and shipped off from the gaseous reagents that failed to react in a previous pass through the reactor. It has been approximated as a flash vessel in ASPEN. HB-S-01 operates at 30 degrees Celsius and a pressure of 40 bar, taking in 968 kmol/hr of reagents, and outputting 69 kmol/hr of liquid ammonia product. HB-S-01 is the first column in the process loop, and as such is responsible for the bulk of the separation of ammonia from other gases. The distillate from HB-S-01 is recycled back into the main process loop after being heated by the reactor products. This occurs in heat exchangers HB-HX-01 and HB-HX-02. The stream is then pressurized by compressor HB-CP-02 to 80 atmospheres of pressure. Some of the unreacted hydrogen and nitrogen will inevitably leave as bottoms products from this first separation tower and enter the next stage. After the liquid product is depressurized in the let-down vessel HB-S-02 (see **Section 7.2.3**), the unreacted reagents (and trace amounts of ammonia) will leave as distillate and be repressurized by the compressor HB-CP-01. The distillate is also partially purged to remove the buildup of inert argon in the system, and the rest of the distillate rejoins the initial feed stream This rejoining of the two streams through a mixer completes the recycling process.

7.2.3 Let Down Vessel (HB-S-02)

The let down vessel, which has been approximated as a flash vessel in ASPEN, is primarily utilized to lower the high pressure of the bottoms product of the separation columns, over 40 atmospheres, into a more manageable pressure for storage and shipment, roughly 10 atmospheres. The majority of the mass that flows through the vessel stays liquified at these conditions, given that almost exclusively liquid ammonia will exit as bottoms products from the columns. A small fraction of the liquid entering will be gasified upon pressure reduction, and will be sent to be repressurized and recycled throughout the process once more.

7.2.4 Compression of Gaseous Reactants (HB-C-01, HB-C-02)

There are two separate compressors that are utilized in the ammonia synthesis portion of the process. In the first cycle through the reactor, there will be no ammonia to separate, and all the gas will flow through to the pre-reactor compressor HB-CP-02, where the gas is pressurized to the required 80 atmospheres of pressure that is required for the reaction to proceed at the desired rate. The second compressor, HB-CP-03, is used to compress the distillate of the let down vessel to return to the conditions needed to be reintroduced to the feed stream.

Due to the high pressures required for the reactants, centrifugal pumps were found to be appropriate. These compressors work through the use of an impeller that is shaped to force the gas to the rim of the impeller, which increases the velocity. This process is done through multiple stages. These compressors are ideal as they are sufficiently large for this process and have comparatively greater efficiencies. They also weigh significantly less and occupy less space than other compressors of similar function, such as reciprocating compressors.

7.2.5 Heat Exchangers (HB-HX-01, HB-HX-02, HB-HX-03, HB-HX-04)

In this process there are a number of situations where it is necessary to change the temperature of a given stream before the next process can be performed. Typically, in order to lower operation costs and purchases of utilities it is effective to exchange heat between a hotter stream that needs to be cooled, and a cooler stream that must be heated. Unfortunately, there are scenarios when no such heat integration opportunities are available, and in these cases a heater or cooler are used. An important note regarding the composition of the heat exchanger, along with the heaters and coolers, is that carbon steel is not an appropriate material choice. The hydrogen that is present all throughout the ammonia synthesis portion of the process is prone to reacting with the carbon in steel, causing hydrogen embrittlement to occur. This is a potential safety hazard because a pipe, or heat exchanger that has been made brittle could eventually burst. This result could be explosive and catastrophic. As such, the choice of material for these processes (and pipings) was chosen to be a Cr-Mo steel alloy that is far more resistant to this problem.

The most significant use of heat integration in this process are the usage of HB-HX-01 and HB-HX-02. The entry temperature of the reagents into the ammonia synthesis process from the SOEC section are high, but not enough to reach the desired reaction conditions. Preheating of these reagent streams is performed by heat exchangers HB-HX-01 and HB-HX-02, which utilize the high temperature of the reaction products to help reach the desired temperature for input into the reaction vessel. The cold reagent stream enters HX-01 at 30 degrees Celsius, and exits at 90 degrees Celsius. After compression the temperature increases again, causing the stream to enter HX-02 at 193 degrees Celsius, and exiting at 225 degrees Celsius. The hot stream analogs to the aforementioned streams are the reaction products, which enter HX-02 at 400 degrees Celsius, and exit at 368 degrees Celsius. This stream is then cooled slightly by HX-03, which is cooled with cooling water, before entering HX-01, exiting at 300 degrees Celsius. Finally, the hot stream reaches HX-04, where it is once again cooled by cooling water until it reaches the final temperature of 250 degrees Celsius.

7.2.6 Storage

The liquid ammonia product, having met the quality criteria for proper sale, is stored in a very large-scale spherical tank. A spherical tank was chosen for the combination of volume, ability to minimize stress from the pressure in the storage vessel, and lack of heat transfer with the surroundings due to minimization of surface area. The tank will be pressurized at 10 atmospheres and held at a temperature of 20 degrees Celsius. The volume of the tank, roughly 47,000 gallons, was calculated to account for a three-day storage time, the longest amount of time that is expected for the tank to be emptied and for product to be shipped off by rail car. This calculation can be found in the *Appendix A.4*. For information regarding how transportation of product is expected to be undertaken can be found in **Section 14.5**.

8. Energy Balance and Utility Requirements

8.1 Description of Partitioning

In this section, the description of the energy balance and the energy requirements for utilities is split into discussions of the first and second "halves" of the process, similarly to what has been done in previous sections of this report, and will be continued in **Sections 9** and **10**. The first half involves the input of the air and water to the system and the utilization of the SOEC, culminating in the output of hydrogen and nitrogen into the Haber-Bosch ammonia synthesis portion, which is the second half of the process.

Overall, operation of this plant process involves a considerable amount of utilities and electricity, notably cooling water, high pressure steam, and electricity. There is also a fired heater that is operated in the first half of the process. While the utilities themselves are inexpensive, the volume that is required to achieve the desired output is considerable, and as such becomes a noticeable expense. Particularly, the incredible pressure requires significant investment in electricity, not to mention the large equipment cost for such a compressor. Yearly figures were calculated assuming that the plant operates for 350 days a year. It is assumed that the electricity will be obtained from renewable energy sources.

8.2.1 Electricity Requirements for Overall Process

It is clear from **Table 8.2.1a** that the large majority of the electricity requirements stem from the hydrogen/nitrogen generation process. The overall amount of energy that the system requires is around 26.7MW.

Table 8.2.1a: Electricity Requirements for Overall Process

Process	Duty [cal/sec]	Usage Rate [kW]	Yearly Consumption [kW-hr]	Yearly Operation Cost [$]
SOEC	4,952,066	20,719	174,043,374	0
HB	1,430,000	5986	50,281,652	0
Total Process	6,382,066	26,705	224,325,026	0

8.2.2 Breakdown of Electricity Requirements for SOEC Processes

A summary of the electricity requirements of the SOEC processes can be found in **Table 8.2.2a**. Some of the largest requirements of energy are the water boiler (UP-BO-01), the SOEC system (SOEC), and the condenser. Since it was assumed that the electricity to power these units and the water was essentially free, it was chosen to add excess water to provide ample quantities for reaction and also to absorb some of the heat released by the oxyhydrogen reaction. The SOEC has an especially high electricity requirement as it is the component directly responsible for producing the hydrogen to be fed into the next step of the overall process. Lastly, a large amount of energy is expended to cool and condense the cathode stream as to limit the dangers of working with hydrogen and eliminate the water.

Table 8.2.2a: Electricity Requirements for SOEC Processes

Unit Operation	Duty [cal/sec]	Usage Rate [kW]	Yearly Consumption [kW-hr]	Yearly Operation Cost [$]
UP-PM-01	5,839	24	205,212	0
UP-BO-01	1,948,510	8,153	68,481,553	0
UP-CP-01	24,642	103	866,040	0
UP-CP-02	28,418	119	998,760	0
UP-CP-03	26,625	111	935,760	0
UP-FH-01	49,497	207	1,739,602	0
SOEC	2,868,069	12,000	100,800,000	0
UP-CP-04	466	2	16447	0
Total	4,952,066	20,719	174,043,374	0

8.2.3 Breakdown of Electricity Requirements for Ammonia Synthesis Processes

Table 8.2.2: Electricity Requirements for Ammonia Processes

Unit Operation	Duty [cal/sec]	Usage Rate [kW]	Yearly Consumption [kW-hr]	Yearly Operation Cost [$]
HB-C-01	743	3.1	26,124	0
HB-C-02	327,500	1,371	11,520,000	0
HB-S-01	788,900	3,303	27,745,200	0
HB-S-02	1,772	7.4	62,328	0
HB-RXN	310,740	1,301	10,928,000	0
Total	1,430,000	5986	50,281,652	0

8.3 Cooling Water Requirements for Overall Process

Table 8.3a: Cooling Water Requirements for Overall Process

Process	Yearly Amount (MT/yr)	Yearly Cost ($)
Cooling Water	280,534	8,000
Chilled Water	140,397	211,000
Chilled Brine	1,008,626	1,512,000
Total	1,429,557	1,731,000

9. Equipment List and Unit Descriptions

9.1 Heuristics for Equipment Determination

Generally, the equipment described and utilized here have had their costs determined through a number of common chemical engineering heuristics and equations. The specifics regarding each piece of equipment, including flow rates, energy usage, as well as temperature and pressure data can be found more clearly in **Section 10: Specification Sheets**.

9.2 Construction Materials

In general, the "cheapest first" heuristic was adhered to regarding our choice of materials for construction. This can be seen in our choice to use cheaper materials whenever possible in our design, such as in the pipes for the water input into the SOEC system where the complications regarding hydrogen are not a concern, stainless steel instead of Mo-Cr alloys can be used. Generally however, most of the processes in this operation involve hydrogen gas, meaning that embrittlement concerns dictate that allows such as Mo-Cr or Monel (nickel alloy) must be used instead.

9.3 Specialized Equipment

Costing heuristics are very useful, and are implemented in this report for the majority of the processes in this design. However, there are specific pieces of equipment in this design which are too specialized to have a heuristic that allows for a rule-of-thumb calculation to be performed. These non-standard pieces of equipment include the air filtration unit, and the solid oxide electrolytic cells. In order to find information and pricing, various online sources and quotes were found for these units, but should be considered to have significantly more variability in these estimations compared to the "actual" price of these units than the more conventional units will. In the ammonia synthesis reactor, information regarding retention time, sizing, and catalyst volume were found from literature.

9.4 Mixers and Splitters

Mixers and splitters must be used throughout the whole process to ensure the system is able to run continuously. In these cases, mixing and splitting can be accomplished by a tee in the pipeline and utilizing a series of analyzers, controllers, and valves. These considerations are expected to be covered by the bare module costs and as such no specific analysis was conducted on these units.

9.5.1 Water Pump (UP-PM-01)

UP-PM-01 will be used to bring liquid water at 25°C and 1 bar up to 40 bar so that it may be incorporated into the process. UP-PM-01 will be a pump with two stages operating at 3600rpm and has a horizontal split case. This pump will be constructed with cast iron. An electric motor that is able to provide 32.75hp will be used to drive these pumps. The cost of the pump itself and the electric motor are $12,748 and $1,733 respectively.

9.5.2 Water Boiler (UP-BO-01)

Following the compression of the water, the water must be transformed to steam and raised to 420°C . The change in temperature is accomplished in a water boiler. Stainless steel will be the material of construction for this unit. The costing of this unit was given the same treatment as the fired heater and determined to be $891,249 dollars.

9.5.3 Compressors (UP-CP-01, UP-CP-02, UP-CP-03, and UP-CP-04)

In order to get the air to a suitable pressure, three different centrifugal compressors are used. The first compressor brings the air from1 bar to 3.42 bar, the second compressor from 3.08 bar to 11.7 bar, and the third compressor from 11.36 bar to 40 bar. This was done in three different steps to avoid having the compression ratio extend beyond 4. These compressors will be constructed out of cast iron. The required power of these compressors are 138.3 hp, 159.5 hp, and 149.4 hp respectively. The fourth compressor in the system (UP-CP-04) will take the stream from 38.93 bar to 40 bar for re-entry into the process. This compresor will also be a centrifugal compressor but will be made of Cr-Mo steel alloy to prevent the embrittlement of the device. The compressor has a shaft power of 2.63 hp. The cost of the compressors is as follows: $223,248; $244,570; $234,696; and $25,785. These prices are in number order of the compressors.

9.5.4 Coolers (UP-CO-01, UP-CO-02, UP-CO-03)

Throughout the SOEC system, streams must be cooled throughout to ensure optimal performance into the next unit or for convenience reasons. In each of these coolers which were shell and tube heat exchangers, the hot stream is fed to the shell side while the coolant is fed through the pipes. UP-CO-01 and UP-CO-02 use cooling water as the coolant and UP-CO-03 uses chilled water. Each of the exchangers was designed with having a fixed head, tube lengths of 20ft, and made of carbon steel on both sides. UP-CO-01 and UP-CO-02 cool the air stream to 37.8°C following their respective compression processes. UP-CO-03 cools the oxygen stream to 35°C. The surface areas of the individual coolers in order are as follows: 2.01 m^2, 3.80 m^2, and 2.94 m^2. The costs of the coolers are as follows: $14,337; $12,328; $14,564,

9.5.5Air Heater (UP-FH-01)

Following the last compressor, the air must be heated so as not to decrease the temperature too far upon mixing with the water, hydrogen, and nitrogen stream. The air stream is raised to a temperature of 550°C from 222.9°C. Stainless steel will be used to construct this air heater. The cost of this unit is $49,920.

9.5.6 Heat Exchangers (UP-HX-01, UP-HX-02)

Heat exchangers are used in the system in order to maximize the extra energy remaining from the outputs from the SOEC systems. As they will exit the SOEC at 800°C and are to be cooled, this heat is used to heat up the water + recycle stream mixture to a temperature high enough (610°C) so that upon mixture with the air, the reaction of hydrogen will release enough heat to raise the temperature to 800°C. The exact nature of these calculations can be found in *Appendix A.2*. The first heat exchanger raises the temperature of the cool stream to 590°C and the second one raises the temperature to 610°C. Similar to the coolers, the heat exchangers are fixed head and the hot stream is run along the shell side while the cold streams are fed through the tube side of the exchanger. The material of construction will be Cr-Mo steel to avoid hydrogen embrittlement problems. The tube length will be 20 ft. The surface areas of UP-HX-01 and UP-HX-02 are 7.06 m^2 and 1.31 m^2. The price of UP-HX-01 is $34,228 and UP-HX-02 is $46,708.

9.5.7 500kW Solid Oxide Electrolyzer (SOEC)

The solid oxide electrolyzers are one of the most important and most expensive units of the process. Each cell stack was given a rating of 500kW to guide calculations. Since technology has not yet advanced this far, systems of these sizes do not yet exist but this model was derived with the assumption that technology will reach these sizes within the near future. Each stack will be run at 1.285V and 384,615 amps. 1.285V was chosen since it is the thermoneutral voltage for the reaction at 800°C. 24 units of 500kW stacks are necessary in order to achieve the hydrogen production desired. Materials used to build these units are going to be assumed to be standard: Ni-YSZ anode with a LSM anode. It is important to note that one of the main technological innovations to drive down costs of these units will be in the material in itself. The estimated bare modular cost of this unit will be $15,000,000. From using a bare modular cost of 2, a purchase cost of $7,500,000 was determined. This was chosen as a rough estimate to two significant figures by using some older SOFC costs as a basis. The authors understand that this number is low for an estimate and will instead focus on a sensitivity analysis on the cost that these units need to be in order for this operation to be profitable in **Section 15**.

9.5.8 Product Stream Condenser (UP-CD-01)

The products exit the cathode side of the electrolyzer with steam needing to be eliminated from the stream prior input to the Haber Bosch process. This is accomplished in a condenser which removes the water as a liquid. The condenser will be made of Cr-Mo steel due to the hydrogen. The cooling fluid for the condenser is chilled brine. The hot stream temperature is lowered to 35°C from 598°C. Costing for this unit was assumed to be similar to a typical heat exchanger and was determined to be $47,353.

9.6.1 Ammonia Synthesis Compressor Units (HB-C-01, HB-C-02, HB-CP-03)

Each of these compressors in the ammonia synthesis process serve to pressurize the nitrogen, hydrogen, and argon that is used in the synthesis operation. Compressor HB-C-01 increases the pressure of it’s outgoing stream by 30 atmospheres, from 10 atm to 40 atm. HB-C-02 increases the pressure of it’s outgoing stream by 40 atmospheres, from 40 atm to 80 atm. These compressors will each be similar in function, and HB-C-01 will be operating at 150 horsepower. HB-CP-02 is the compressor that must put in the most work, and as such will be larger in size as well, and will operate at 1500 horsepower. Each compressor will utilize 8000-hour synthetic oil, and motors made of cast iron. HB-CP-01 will cost $14,021 and HB-CP-02 will cost $1,405,174 to purchase.

9.6.2 Heat Exchanger 1 (HB-HX-01, HB-HX-02, HB-HX-03, HB-HX-04)

Heat exchangers and associated pumps are required to facilitate the function of the synthesis process. The ammonia synthesis reactor output products are too hot to be placed in the separation column, and as such are cooled by contacting the input streams, heating them in the process to reaction conditions, which is done by heat exchangers HB-HX-01 and HB-HX-02. HB-HX-01 is 25 m^2 in surface area, and HB-HX-02 is 79 m^2 in surface area. Both are fixed head, shell-and-tube heat exchangers, 20 meters in length, and with both being made of Cr-Mo steel. In both cases, the hot stream is in the tube side, and the cold stream is in the shell side. HB-HX-01 cost $33,407 and HB-HX-02 cost $40,114 to purchase. The other two heat exchangers, HB-HX-03 and HB-HX-04 are similar in function to the previous exchangers, cooling the product stream to the proper temperatures to enter the separation units. They differ however in using cooling water instead of the colder reactant stream as the cooling fluid, and as such have the hot fluid in the shell. HB-HX-03 and HB-HX-04 are both 20 meters in length, and made of Cr-Mo steel on the gaseous product side, and carbon steel on the cooling water side. HB-HX-03 has a surface area of 25 m^2, operates at 508 psig, and will cost $37,992 to purchase. HB-HX-04 is identical to HB-HX-03 in terms of length and area, but operates at 1160 psig, and will cost $48,292 to purchase.

9.6.3 Ammonia Synthesis Reaction Vessel (HB-RXN)

The ammonia synthesis reaction vessel is a packed bed reactor. The reaction that occurs is the conversion of gaseous nitrogen and hydrogen into ammonia, which is highly exothermic and proceeds under pressure greater than 80 atmospheres. This reaction is catalyzed by the presence of a sodium-doped iron catalyst which facilitates the splitting of the diatomic hydrogen and nitrogen gas into constituent atoms. The reactor has a capacity of 2.63 m^3 and produces 84 kmol of ammonia per hour. This value was determined using residence time information about the reaction. To determine the catalyst mass, GHSV data and volume of catalyst in the reactor were taken from literature, and the final mass was determined to be 316 kg. The reactor vessel is a vertical pressure vessel that is 14.35 feet in height and 2.87 feet in diameter, and the vessel is made of Monel to account for the problem of hydrogen embrittlement. The total cost of this reaction vessel is $81,929.

9.6.4 Separation Columns (HB-S-01, HB-S-02)

The first separation vessel, HB-S-01, is used to take in the input stream along with the product of the reaction vessel and separate the liquid ammonia off from the gaseous reactants. The liquid ammonia product is sent directly to HB-S-02, which serves as a let-down vessel. This vessel depressurizes the ammonia product and allows it to be safely stored at sale conditions in a spherical storage tank. There will be a small amount of distillate from HB-S-02, but not very much, as little H_2 or N_2 will have been liquified and carried to the let-down vessel. This minute amount of gaseous reactants will be recompressed and recycled back with the input stream to begin the cycle anew. HB-S-01 will be operated at 25 degrees Celsius and at a pressure of 40 atmospheres. HB-S-01 is a vertical pressure vessel with a diameter of 0.87 ft, and a height of 10.37 feet. This vessel, along with HB-S-02, is made of Monel-400 to prevent hydrogen embrittlement. HB-S-02 is operated at a slightly higher temperature, at around 50 degrees

Celsius, and at a lower pressure of 10 atmospheres. This column has a diameter of 0.78 feet and a length of 12.16 feet. HB-S-01 costs $15,871 to purchase, and HB-S-02 costs $13,735 to purchase.

9.6.5 Storage Vessel

The ammonia storage vessel is a spherical vessel. The volume of the vessel was calculated by considering the retention time required to store the output of this process for a relatively long period of time, in case pickup and shipment of the product is halted for a few days. The calculations to determine this volume can be found in the *Appendix.* A spherical vessel was chosen due to the large volume of this storage vessel, but also the ability for a spherical vessel to withstand the pressure that the product is stored at, as well as to minimize heat transfer with the surroundings. The vessel is pressurized at 10 atmospheres, and is constructed of Monel to avoid hydrogen causing cracks in the storage vessel over time. The cost of this spherical storage vessel is $235,000.

10. Specification Sheets

Input Water Pump (UP-PM-01)

Description and Function

Increases the pressure of the water input stream from 1 bar to 40 bar.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Water

Characteristics

Material: Cast Iron, Pump Type: Centrifugal pump, Number of Stages: 2 stages, Split Case Type: Horizontal Split Case, Pump Specs: 3600 rpm, Power: 32.75 hp,

Operating Conditions/Design Data

Temperature: 25°C - 26.2°C

Pressure: 1 bar - 40 bar

Purchase Cost

$ 12,748

Utilities

24.43 kW electricity

Water Pump Motor (UP-EM-01)

Description and Function

Electric motor used to drive the water pump.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Water

Characteristics

Power: 32.75 hp

Operating Conditions/Design Data

N/A

Purchase Cost

$1,733

Utilities

24.43 kW electricity

Input Water Boiler (UP-BO-01)

Description and Function

Following pressurization of the water, the water is transformed to steam and heated to 420°C.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Water

Characteristics

Material: Stainless Steel, Process Volume: 2964.8 gal/min

Operating Conditions/Design Data

Temperature: 26.2°C - 420°C

Purchase Cost

$891,249

Utilities

1,9948,510 kW electricity

Air Filter

Description and Function

Filters the air prior to entry into the system.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Nitrogen, Oxygen, Argon

Characteristics

Process Volume: 3400 m^3, Filter Media Material: Glass Fiber, Filter Class: M6, Media area: 8 m^2, Filter Type: Vbank filter Dimensions: 0.6 x 0.6 x 0.2 m, Air flow: 3,400 m3/hr Frame: ABS, Weight: 3 kg

Operating Conditions/Design Data

Temperature: 25°C

Pressure: 1 bar

Purchase Cost

$4,000

Utilities

N/A

Air Compressor 1 (UP-CP-01)

Description and Function

Compresses ambient air at 1 bar to 3.42 bar.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Nitrogen, Oxygen, Argon

Characteristics

Material: Cast Iron, Type: Centrifugal Compressor, Power: 138.3 hp

Operating Conditions/Design Data

Temperature: 25°C - 197.9°C

Pressure: 1 bar - 3.42 bar

Purchase Cost

$223,248

Utilities

103 kW electricity

Air Compressor 2 (UP-CP-02)

Description and Function

Compresses the air from 3.08 bar to 11.7 bar following a decrease in temperature from a cooler.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Nitrogen, Oxygen, Argon

Characteristics

Material: Cast Iron, Type: Centrifugal Compressor, Power: 159.5 hp

Operating Conditions/Design Data

Temperature: 37.8°C - 236.2°C

Pressure: 3.08 bar - 11.7 bar

Purchase Cost

$244,570

Utilities

119 kW electricity

Air Compressor 3 (UP-CP-03)

Description and Function

Compresses the air from 11.36 bar to 40 bar following a decrease in temperature from a cooler.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Nitrogen, Oxygen, Argon

Characteristics

Material: Cast Iron, Type: Centrifugal Compressor, Power: 149.4 hp

Operating Conditions/Design Data

Temperature: 37.8°C - 222.9°C

Pressure: 11.36 bar - 40 bar

Purchase Cost

$234,696

Utilities

111 kW electricity

Recycle Stream Compressor (UP-CP-04)

Description and Function

Compresses the recycle stream back up to 40 bar following pressure drops throughout the process.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon

Characteristics

Material: Cr-Mo Steel, Type: Centrifugal Compressor, Power: 2.63 hp

Operating Conditions/Design Data

Temperature: 35°C - 36.2°C

Pressure: 38.9 bar - 40 bar

Purchase Cost

$25,785

Utilities

1.95 kW electricity

Air Cooler 1 (UP-CO-01)

Description and Function

Cools the air exiting Air Compressor 1 (UP-CP-01) to 37.8°C to reduce energy requirements on subsequent compressor.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Nitrogen, Oxygen, Argon

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 2 m^2 Tube Side Material: Carbon Steel, Shell Side Material: Carbon Steel, Tube length: 20 m

Operating Conditions/Design Data

Hot Side Temperature: 197.9°C - 37.8°C

Hot Side Pressure: 3.42 bar - 3.08 bar

Purchase Cost

$14,337

Utilities

63,601 MT/Year Cooling Water

Air Cooler 2 (UP-CO-02)

Description and Function

Cools the air exiting Air Compressor 2 (UP-CP-02) to 37.8°C to reduce energy requirements on subsequent compressor.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Nitrogen, Oxygen, Argon

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 3.8 m^2 Tube Side Material: Carbon Steel, Shell Side Material: Carbon Steel, Tube length: 20 m

Operating Conditions/Design Data

Hot Side Temperature: 236.2°C - 37.8°C

Hot Side Pressure: 11.7 bar - 11.36 bar

Purchase Cost

$12,328

Utilities

63,601 MT/Year Cooling Water

Oxygen Cooler (UP-CO-03)

Description and Function

Cools oxygen product stream from the SOEC for easy storage.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Oxygen

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 2.9 m^2 Tube Side Material: Carbon Steel, Shell Side Material: Carbon Steel, Tube length: 20 m

Operating Conditions/Design Data

Hot Side Temperature: 650°C - 35.0°C

Pressure: 39.0 bar - 38.9 bar

Purchase Cost

$14,564

Utilities

140,397 MT/Year Chilled Water

Air Heater (UP-FH-01)

Description and Function

Heats up the air following the compression steps.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Nitrogen, Oxygen, Argon

Characteristics

Material: Stainless Steel, Volume Processed: 559.2 gal/min

Operating Conditions/Design Data

Temperature: 222.9°C - 550.0°C

Purchase Cost

$49,920

Utilities

207 kW electricity

Heat Exchanger 1 (UP-HX-01)

Description and Function

Takes the compressed and heated water stream as the cold stream and the cathode product stream as the hot stream. Most of the heat exchange is done here.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hot Stream: Water, Hydrogen, Nitrogen, Argon

Cold Stream: Water, Hydrogen, Nitrogen, Argon

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 7 m^2 Tube Side Material: Cr-Mo Steel, Shell Side Material: Cr-Mo Steel, Tube length: 20 m

Operating Conditions/Design Data

Cold Stream Temperature: 379.9°C - 590.0°C

Cold Stream Pressure: 40.0 bar - 39.7 bar

Purchase Cost

$34,228

Utilities

N/A

Heat Exchanger 2 (UP-HX-02)

Description and Function

Takes the compressed and heated water stream as the cold stream and the oxygen product stream as the hot stream.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hot Stream: Oxygen

Cold Stream: Water, Hydrogen, Nitrogen, Argon

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 1.3 m^2 Tube Side Material: Cr-Mo Steel, Shell Side Material: Carbon Steel, Tube length: 20 m

Operating Conditions/Design Data

Cold Stream Temperature: 590.0°C - 610°C

Cold Stream Pressure: 39.7 bar - 39.3 bar

Purchase Cost

$ 46,708

Utilities

N/A

500kW Solid Oxide Electrolyzer (SOEC)

Description and Function

This unit electrolyzes water to produce hydrogen. Each stack is input with 25.87 kmol/hr (14.63 kmol H_2O/hr, 7.96 kmol H_2/hr, 3.24 kmol O_2/hr, 0.037 kmol Ar/hr). A total of 7.13 kmol H_2/hr and 3.56 kmol O_2/hr gets produced and within each stack. There are 24 stacks in the system.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Cathode Side: Water, Hydrogen, Nitrogen, Oxygen, Argon. Anode Side: Oxygen

Characteristics

Anode: Ni-YSZ, Cathode: LSM

Operating Conditions/Design Data

Temperature: 800°C

Voltage: 1.285V

Current: 384,615 Amps

Purchase Cost

$7,500,000 (estimation) Bare Module Cost: $15,000,000

Utilities

500 kW electricity per stack (12MW total)

Product Stream Condenser (UP-CD-01)

Description and Function

Condenses the product stream so the water can easily be separated and the hydrogen can be handled easier.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Gaseous: Hydrogen, Nitrogen, Argon

Liquid: Water

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 66 m^2 Tube Side Material: Carbon Steel, Shell Side Material: Cr-Mo Steel, Tube length: 20 m

Operating Conditions/Design Data

Hot Stream Temperature: 598.2°C - 35.0°C

Hot Stream Pressure: 39.0 bar - 38.9 bar

Purchase Cost

$ 47,353

Utilities

1,008,626 MT/year Chilled Brine

Pre-Reaction Vessel Compressor (HB-CP-02)

Description and Function

This compressor serves to increase the pressure of the distillate of the first separation column to the required 80 atmospheres of pressure for the ammonia synthesis reaction to proceed.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Material: Cr-Mo Steel, Weight: 2.5 MT, Compressor Type: Centrifugal Pump, Oil Type: 8000-hour synthetic, 1500 hp

Operating Conditions/Design Data

Temperature: 175°C

Pressure: 40 atm - 80 atm

Purchase Cost

$1,405,174

Utilities

1371 kW electricity

Let-Down Vessel Distillate Compressor (HB-CP-01)

Description and Function

This compressor serves to increase the pressure of the distillate of the let down vessel to 10 atmospheres before entering the secondary separation unit.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Material: Cr-Mo Steel, Weight: 1.5 MT, Compressor Type: Centrifugal Pump, Oil Type: 8000-hour synthetic, 150 hp

Operating Conditions/Design Data

Temperature: 50°C

Pressure: 10 atm - 40 atm

Purchase Cost

$14,021

Utilities

3.1 kW electricity

Separation Column (HB-S-01)

Description and Function

The first separation column removes the bulk of the unreacted inputs from the liquid ammonia product. The distillate of this column is recycled back to the reactor after subsequent heatings and repressurization. The bottoms product is piped to the let down vessel for further purification and depressurization.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Material: Monel, Number of Trays: 8, Feed Stage: 4, Diameter: 0.87 ft, Height: 10.37 ft, Tray Efficiency: 0.5, Reflux Ratio: 10.5, Condenser: Total

Operating Conditions/Design Data

Temperature: 25°C, Pressure: 40 atm, Mass Flow Rate: 8,653 kg/hr

Mole Flow Rate: 1,119 kmol/hr Mass Flow Hydrogen: 1,251 kg/hr, Mass Flow Nitrogen: 5,800 kg/hr,

Mass Flow Ammonia: 1,763 kg/hr. Mass flow Argon: 5 kg/hr

Purchase Cost

$15,871

Utilities

3,303 kW electricity

Let Down Column (HB-S-02)

Description and Function

This column serves to depressurize the bottoms product of HB-S-01 to allow the liquid ammonia to be removed for storage and later shipment

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Material: 304 Stainless Steel, Number of Trays: 6, Feed Stage: 3, Diameter: 0.78 ft, Height: 12.16 ft, Tray Efficiency: 0.5, Reflux Ratio: 7.5, Condenser: Total

Operating Conditions/Design Data

Temperature: 50°C, Pressure: 10 atm, Mass Flow Rate: 1873 kg/hr

Mole Flow Rate: 124 kmol/hr Mass Flow Hydrogen: 28 kg/hr, Mass Flow Nitrogen: 116 kg/hr, Mass Flow Ammonia: 1729 kg/hr. Mass flow Argon: 0.05 kg/hr

Purchase Cost

$13,735

Utilities

74 kW electricity

Heat Exchanger (HB-HX-01)

Description and Function

This first heat exchanger heats the distillate of the first separation column using heat energy from the reaction products.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 24 m^2 Tube Side Material: Cr-Mo Steel, Shell Side Material: Cr-Mo Steel, Tube length: 20 m, Tube Diameter: 4.54 cm,

Operating Conditions/Design Data

Cold Side Output Temperature: 125°C

Pressure: 490 psig

Purchase Cost

$40,114

Utilities

N/A

Heat Exchanger (HB-HX-02)

Description and Function

This second heat exchanger further heats the distillate of the first separation column using heat energy from the reaction products after compression to prepare the cooler stream for entry to the reaction vessel

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 79 m^2 Tube Side Material: Cr-Mo Steel, Shell Side Material: Cr-Mo Steel, Tube length: 20 m, Tube Diameter: 4.88 cm,

Operating Conditions/Design Data

Cold Side Output Temperature: 225°C

Pressure: 1176 psig

Purchase Cost

$33,407 per unit

Utilities

N/A

Heat Exchanger (HB-HX-03)

Description and Function

This heat exchanger serves as a cooler, further removing heat from the product stream after transferring some heat to the input to the reactor vessel, but before it must enter the separation vessel.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 25 m^2 Tube Side Material: Cr-Mo Steel, Shell Side Material: Carbon Steel, Tube length: 20 m, Tube Diameter: 4.73 cm,

Operating Conditions/Design Data

Cold Side Output Temperature: 300°C

Pressure: 490 psig

Purchase Cost

$37,992 per unit

Utilities

120,272 MT/year of cooling water

Heat Exchanger (HB-FH-03)

Description and Function

This heat exchanger serves to even further cool the product of the reaction vessel, bringing the components close to the temperature required for separation.

Vendor

N/A

Operation

Continuous Output

Materials Handled

Hydrogen, Nitrogen, Argon, Ammonia

Characteristics

Type: Shell in tube, fixed head. Effective Surface Area: 25 m^2 Tube Side Material: Cr-Mo Steel, Shell Side Material: Carbon Steel, Tube length: 20 m, Tube Diameter: 5.31 cm,

Operating Conditions/Design Data

Cold Side Output Temperature: 150°C

Pressure: 490 psig

Purchase Cost

$48,292 per unit

Utilities

160,262 MT/year of cooling water

Ammonia Storage Vessel

Description and Function

Spherical 47,000 gallon storage for anhydrous liquid ammonia product, held as a liquid under pressure prior to transportation via rail cart.

Vendor

N/A

Operation

Batch Output, Continuous Input

Materials Handled

Ammonia

Characteristics

Material: Monel, Volume: 48,000 gallons, Working Capacity 66%,

Flow Capability: 3500 kg NH_3/hr

Operating Conditions/Design Data

Temperature: 20°C

Pressure: 10 atm

Maximum retention time: 72 hours

Purchase Cost

$235,000 per unit

Utilities

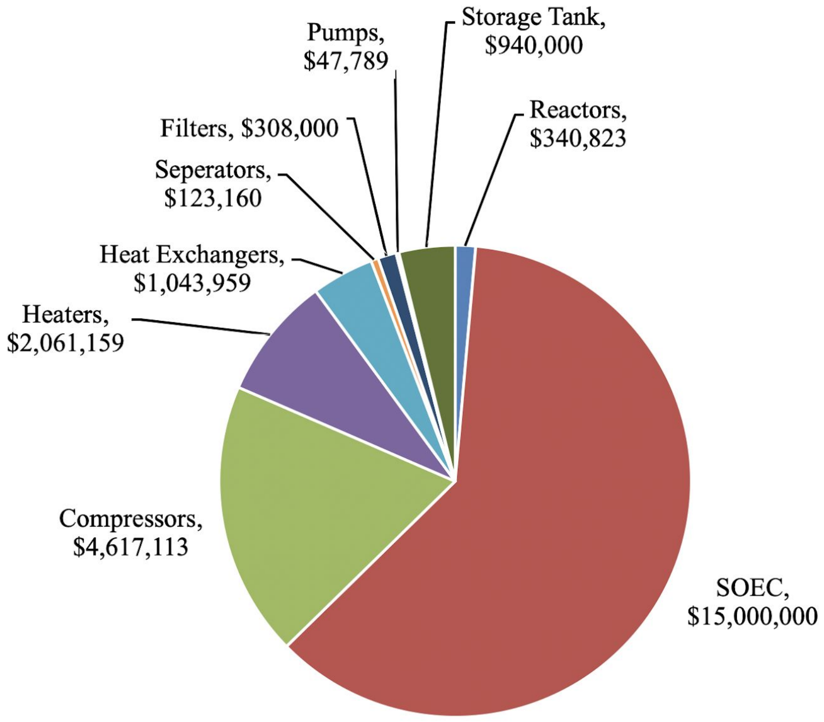
N/A

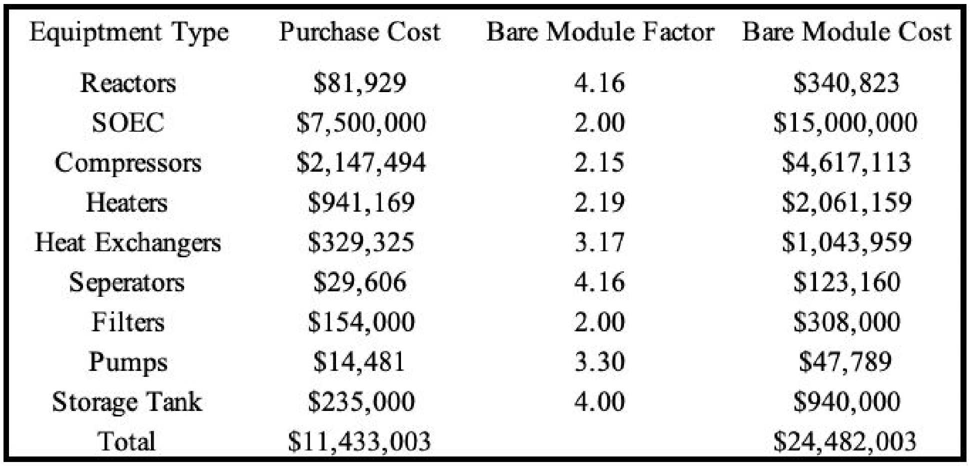
11. Equipment Cost Summary

11.1 Overview

Overall, equipment for the construction of the full green ammonia plant will cost $24.5 million. For simplifying purposes, the process can be broken up into an upstream and downstream portion. The upstream portion includes the part of the process which converts air and water into a hydrogen and nitrogen mixed stream. The downstream portion of the plant includes the conversion of elemental hydrogen and nitrogen into ammonia via the Haber Bosch process.

Figure 11.1a: Breakdown of equipment costs by type of equipment





Equiptment Type	Purchase Cost	Bare Module Factor	Bare Module Cost
Reactors	$81,929	4.16	$340,823
SOEC	$7,500,000	2.00	$15,000,000
Compressors	$2,147,494	2.15	$4,617,113
Heaters	$941,169	2.19	$2,061,159
Heat Exchangers	$329,325	3.17	$1,043,959
Seperators	$29,606	4.16	$123,160
Filters	$154,000	2.00	$308,000
Pumps	$14,481	3.30	$47,789
Storage Tank	$235,000	4.00	$940,000
Total	$11,433,003		$24,482,003

As seen in **Figure 11.1a**, the reactor and the SOECs make up the bulk of the equipment costs. As SOECs become cheaper, this process will become more economical.

11.2 Upstream Equipment Costs

Table 11.2a: Overview of Upstream Equipment Costs

Equipment Description	Type	Purchase Cost	Bare Module Factor	Bare Module Cost
SOEC	Process Machinery	$7,500,000	2.00	$15,000,000
UP-EM-01	Process Machinery	$1,733	3.30	$5,720
UP-PM-01	Process Machinery	$12,748	3.30	$42,068
UP-CP-01	Process Machinery	$223,248	2.15	$479,984
UP-CP-02	Process Machinery	$244,570	2.15	$525,826
UP-CP-03	Process Machinery	$234,696	2.15	$504,596
UP-CP-04	Process Machinery	$25,785	2.15	$55,437
UP-HX-01	Process Machinery	$34,228	3.17	$108,504
UP-HX-02	Process Machinery	$46,708	3.17	$148,064
UP-CO-01	Process Machinery	$14,337	3.17	$45,449
UP-CO-02	Process Machinery	$12,328	3.17	$39,081
UP-CO-03	Process Machinery	$14,564	3.17	$46,168
UP-CD-01	Process Machinery	$47,353	3.17	$150,110
UP-BO-01	Process Machinery	$891,249	2.19	$1,951,834
UP-FH-01	Process Machinery	$49,920	2.19	$109,325
M6 Filter	Process Machinery	$4,000	2.00	$8,000
Ion Exchange Unit	Process Machinery	$150,000	2.00	$300,000
TOTAL				**$19,520,167**

The upstream part of the process is dominated by the SOEC units, whose projected bare module cost is $15 million. All equipment sizing and bare module factors were consistent with Dr. Warren Seider's textbook: "Product and Process Design Principles", 4th edition, 2016..

11.3 Downstream Equipment Costs

Table 11.3a: Overview of Downstream Equipment Costs

Equipment Description	**Type**	**Purchase Cost**	**Bare Module Factor**	**Bare Module Cost**
Haber Bosch Reactor	Process Machinery	$81,929	4.16	$340,823
Sodium Doped Iron Catalyst	Catalysts	$20,000	1.00	$20,000
HB-CP-01	Process Machinery	$14,021	2.15	$30,146
HB-CP-02	Process Machinery	$1,405,174	2.15	$3,021,123
HB-HXA-01	Process Machinery	$40,114	3.17	$127,161
HB-HXA-02	Process Machinery	$33,407	3.17	$105,901
HB-HXA-03	Process Machinery	$48,292	3.17	$153,087
HB-HXA-04	Process Machinery	$37,992	3.17	$120,435
HB-S-01	Process Machinery	$15,871	4.16	$66,024
HB-S-02	Process Machinery	$13,735	4.16	$57,136
Storage Tank	Storage	$235,000	4.00	$940,000
TOTAL				**$4,981,836**

Equipment in the downstream vertical is less expensive. The reactor itself costs $340k, and the process requires multiple compressors that cost in excess $1 million. As mentioned, all machinery in contact with high pressure hydrogen needs to be manufactured from Cr-Mo steel, which is 40% more expensive than carbon steel, adding an additional cost. A spherical storage tank is necessary for storing liquid ammonia, and is particularly expensive as well.

12. Fixed Capital Investment Summary

In order to consider the total permanent investment of this proposal, the cost of land, royalties and startup must be considered as well as equipment and installation costs (**Section 11**).

12.1 Land

In theory, this proposal is meant to be built on the existing site of a coastal windfarm's port. For this reason, it is assumed that a firm undertaking this project would already own the land on which this is meant to be built. For this reason, land was assumed to be 0.5% of total depreciable capital, one-fourth of the default value. This allotment is meant to allow for the purchase of additional land, which should be marginal and significantly less than if this project were designed to be standalone.

12.2 Royalties

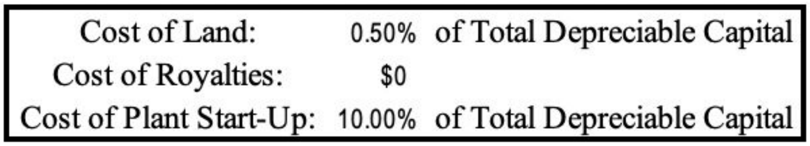
No proprietary technology will be used in the production of ammonia. For this reason, royalties were assumed to be zero in calculating total permanent investment, as is most common.

12.3 Startup

Due to the massive nature of a factor producing 16,000 metric tonnes of ammonia per year, start up costs are significant and must be considered. It was assumed that start up costs would be equal to 10% of total depreciable capital, which should be more than sufficient for starting the plant.

In order to lessen startup costs, the plant will be run constantly, which will lessen effects of startup and reduce costs.

Table 12.3a: An overview of Fixed Capital Investment



Cost of Land:	0.50%	of Total Depreciable Capital
Cost of Royalties:	$0	
Cost of Plant Start-Up:	10.00%	of Total Depreciable Capital

13. Operating Cost

13.1 Raw Materials

Green ammonia is produced only from water, air and wind power. Air and water must be purified before being fed into the process. An air filter and an ion exchange system have been included in our process to be sure the raw material fed will not degrade any equipment or the ultimate product. Raw material costs are therefore assumed to be zero.

Although it has been found that only an ion exchange system will be necessary for this process, a unit that deionizes water may be necessary based on the water quality at the chosen site. Water could be particularly saline (or perhaps even sea water). A cost of such a unit would be minimal in comparison to the rest of the equipment, and could be easily sourced and entered into the process.

13.2 Utilities

Total utility costs come to \$1.7M/yr. Electricity is assumed to be free of charge from a nearby wind farm with excess amounts of electricity. For this reason, only cooling water, chilled water and chilled brine are expenses. For the annual production of 16,000 metric tons of ammonia, utility requirements and prices are below.

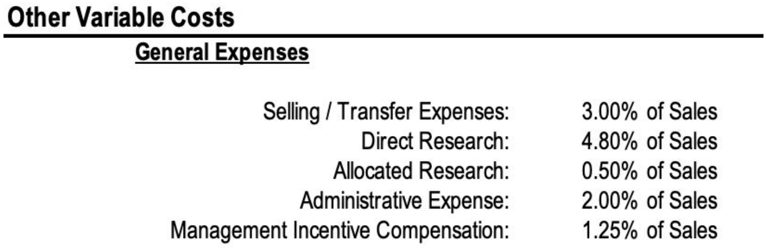
Table 13.2a: Yearly utility amounts and costs

Process	Yearly Amount (MT/yr)	Cost per MT	Yearly Cost ($)
Cooling Water	280,534	$0.027	8,000
Chilled Water	140,397	$1.50	211,000
Chilled Brine	1,008,626	$1.50	1,512,000
Total	1,429,557		1,731,000

13.3 Variable Cost and Working Capital

Additional variable costs were accounted for as follows in **Table 13.3a** Typical values from Seider (2016) were used. Furthermore, working capital considerations and final figures are tabulated in 16.3.2 and 16.3.3. All working capital was expected to be wound down in the 15th and final year of production, 2036.

Table 13.3a: An overview of additional variable costs.

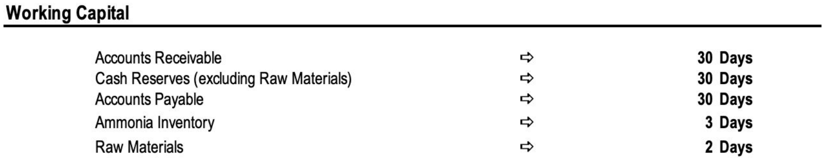


Other Variable Costs

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

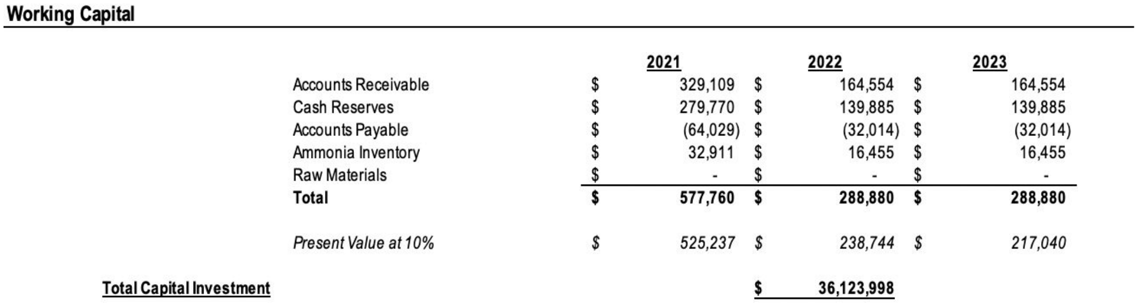
Table 13.3b: An overview of working capital considerations.



Working Capital

Accounts Receivable	➪	**30 Days**
Cash Reserves (excluding Raw Materials)	➪	**30 Days**
Accounts Payable	➪	**30 Days**
Ammonia Inventory	➪	**3 Days**
Raw Materials	➪	**2 Days**

Table 13.3c: Working capital figures.



Working Capital

		2021	2022	2023
	Accounts Receivable	$ 329,109	$ 164,554	$ 164,554
	Cash Reserves	$ 279,770	$ 139,885	$ 139,885
	Accounts Payable	$ (64,029)	$ (32,014)	$ (32,014)
	Ammonia Inventory	$ 32,911	$ 16,455	$ 16,455
	Raw Materials	$ -	$ -	$ -
	Total	**$ 577,760**	**$ 288,880**	**$ 288,880**
	Present Value at 10%	*$ 525,237*	*$ 238,744*	*$ 217,040*
Total Capital Investment			**$ 36,123,998**	

13.4 Total Variable Cost Summary

Variable costs were calculated to be $2M annually. These costs were predominantly comprised of cooling water, chilled water and chilled brine requirements. Oxygen production was calculated to be a byproduct of ammonia production. $700k of oxygen would be produced annually, which counted as a credit against variable costs.

Table 13.4a: Summary of variable costs.

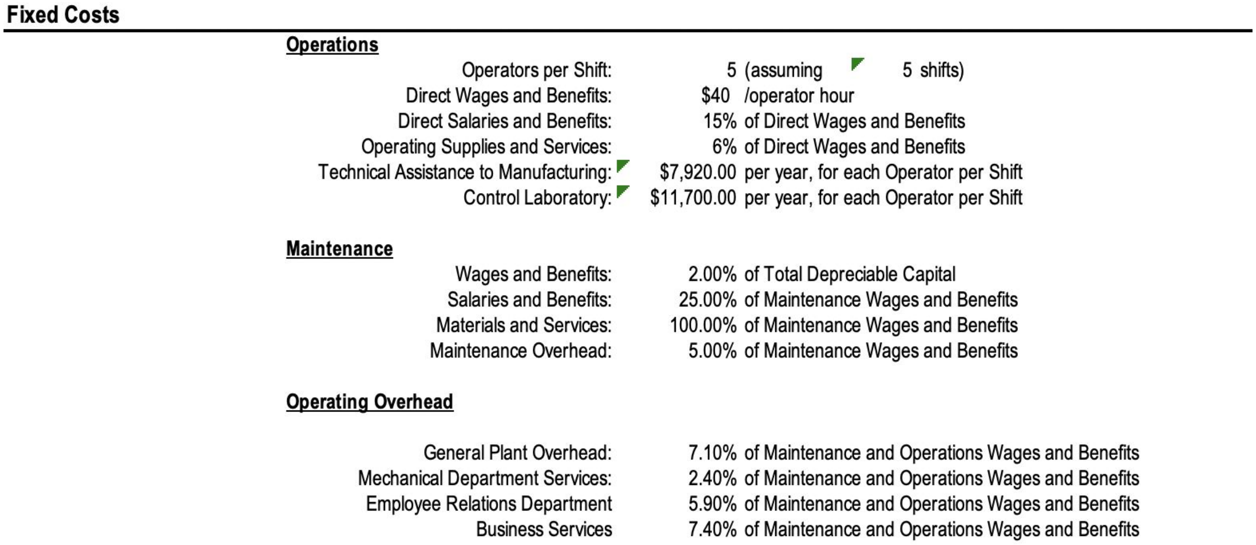
Variable Cost Summary

Variable Costs at 100% Capacity:			
General Expenses			
Selling / Transfer Expenses:		$	266,944
Direct Research:		$	427,110
Allocated Research:		$	44,491
Administrative Expense:		$	177,962
Management Incentive Compensation:		$	111,227
Total General Expenses		$	1,027,733
Raw Materials	$0.00 per ton of Ammonia		$0
Byproducts	$44.00 per ton of Ammonia		($711,850)
Utilities	$107.00 per ton of Ammonia		$1,731,152
Total Variable Costs		**$**	**2,047,035**

13.5 Operations, Maintenance and Overhead

Per shift, 5 operators are needed to run the plant. This was calculated to be 2 operators in both the upstream and downstream verticals and an additional operator monitoring the overall process and deliveries. Technical assistance and the control lab costs were calculated to be ~$200k and ~$300k respectively, consisting of one engineer and a part time lab employee. Default values from Seider (2016) were used in calculated maintenance and operating overhead costs.

Table 13.5a: Overview of operations, maintenance and overhead costs.

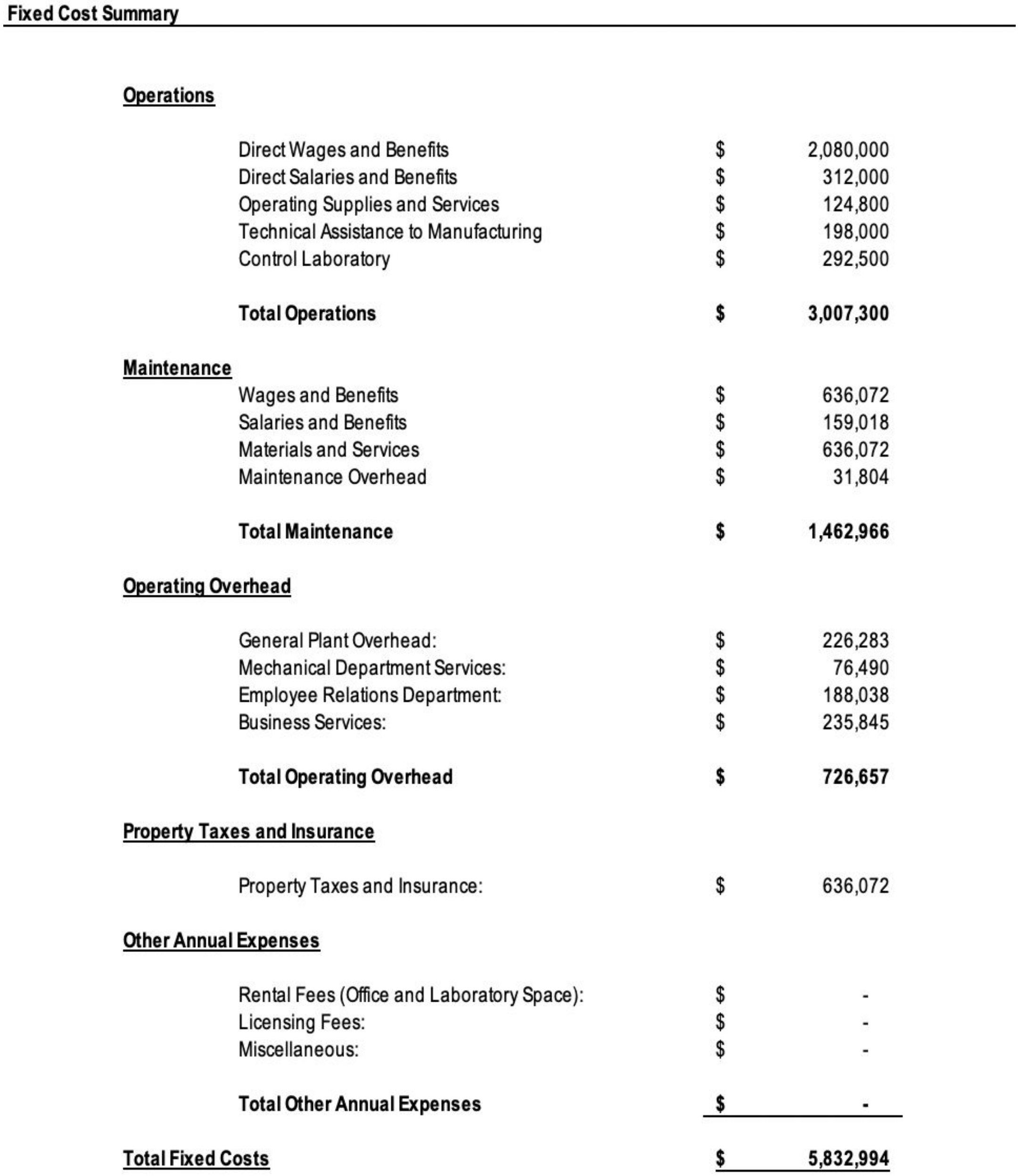


Fixed Costs			
Operations			
	Operators per Shift:	5	(assuming 5 shifts)
	Direct Wages and Benefits:	$40	/operator hour
	Direct Salaries and Benefits:	15%	of Direct Wages and Benefits
	Operating Supplies and Services:	6%	of Direct Wages and Benefits
	Technical Assistance to Manufacturing:	$7,920.00	per year, for each Operator per Shift
	Control Laboratory:	$11,700.00	per year, for each Operator per Shift
Maintenance			
	Wages and Benefits:	2.00%	of Total Depreciable Capital
	Salaries and Benefits:	25.00%	of Maintenance Wages and Benefits
	Materials and Services:	100.00%	of Maintenance Wages and Benefits
	Maintenance Overhead:	5.00%	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

13.6 Total Fixed Costs

Final annual fixed costs resulting from operations maintenance and operating overhead are tabulated in table 13.6a. Due to the large amount of manpower to effectively run this plant, annual fixed costs are expensive at $5.8M/yr. This is the second largest financial hurdle to this plant, after the cost of the SOECs. If the plant were to be scaled up, but was run with the same 25 weekly operators, margins would drastically improve, and the venture would be more profitable.

Table 13.6a: Overview of operations, maintenance and overhead costs.



Fixed Cost Summary

Operations			
	Direct Wages and Benefits	$	2,080,000
	Direct Salaries and Benefits	$	312,000
	Operating Supplies and Services	$	124,800
	Technical Assistance to Manufacturing	$	198,000
	Control Laboratory	$	292,500
	Total Operations	**$**	**3,007,300**
Maintenance			
	Wages and Benefits	$	636,072
	Salaries and Benefits	$	159,018
	Materials and Services	$	636,072
	Maintenance Overhead	$	31,804
	Total Maintenance	**$**	**1,462,966**
Operating Overhead			
	General Plant Overhead:	$	226,283
	Mechanical Department Services:	$	76,490
	Employee Relations Department:	$	188,038
	Business Services:	$	235,845
	Total Operating Overhead	**$**	**726,657**
Property Taxes and Insurance			
	Property Taxes and Insurance:	$	636,072
Other Annual Expenses			
	Rental Fees (Office and Laboratory Space):	$	-
	Licensing Fees:	$	-
	Miscellaneous:	$	-
	Total Other Annual Expenses	**$**	**-**
Total Fixed Costs		**$**	**5,832,994**

14. Other Important Considerations

14.1 Location

One of the earliest and most crucial decisions that was made when researching this project was the choice of plant location. It was immediately obvious that the ending metrics of economic feasibility, plant size, and production capacity are all factors that are directly affected and can be optimized through careful consideration of optimal plant locations. We chose to locate our plant on the coast of Norway, as their agricultural market has sufficient demand such that our capacity of ammonia production would be purchased in its entirety. Furthermore, Norway has a long history of taxing carbon-heavy chemical production facilities at a very high rate. As a “green” ammonia production facility, our plant would avoid these taxes, and would qualify for a number of monetary rewards as a result of our zero-carbon emission plant design. These additional advantages that our plant design has over conventional ammonia synthesis facilities allows us to close the monetary gap that is created by our more expensive production methods.

Norway also has a climate that is conducive to the main reaction being performed in our plant. The synthesis of ammonia from hydrogen and nitrogen is an extremely exothermic reaction, performed at high pressures. With an average temperature of just 5 degrees Celsius, the environment will be a useful asset to lower the amount of work that must be put in by the cooling towers in the process.

The choice of our location to be coastal is a result of the input to our process, as well as our energy needs. One of the inputs into our process is water, and as such the plant will be built coastally to lower transportation costs. Additionally, the coastal location allows for local utilization of the wind power that is stored on offshore, near coast windmills.

These windmills are perhaps the most important reason why Norway was chosen. Norway has massively invested in renewables energy sources, with wind energy at the forefront. The amount of wind energy produced is sufficiently large that it often exceeds energy demand in the country, and as such is simply wasted. Our process utilizes a tiny percentage of this excess wind energy and uses it to power our solid oxide electrolytic cell, which removes an incredible amount of energy that would otherwise need to be sourced through other, less environmentally friendly, means.

14.2 Environmental Impact

One of the key considerations that was made when designing this plant was to ensure environmental friendliness wherever possible, while still reaching the desired output of 46 metric tons of ammonia per day. The ammonia that is produced from our process design utilizes nitrogen from air that has been separated from oxygen, and hydrogen that has been produced through electrolysis of water. Neither of these processes involve the output of pollutants, which is a noticeable environmental improvement over the typical method used to produce hydrogen, which is through steam reformation. Steam reformation outputs carbon monoxide and dioxide, which are greenhouses gases, whereas electrolysis outputs pure oxygen, which in our plant design will be sold as an additional revenue stream. Additionally, the energy requirements being met through the excess wind power that is available in Norway allows for the plant to produce no pollution, a vast upgrade to other traditional plants.

In order to facilitate the small environmental impact of this process, it is important to lower our energy costs as much as possible in order to diminish the need for energy outside of the excess wind power. This excess power would likely need to be produced in less environmentally agreeable ways such as through combustion of fuels like coal or natural gas. This was done by ensuring that the efficiencies of our processes were made as high as possible, through the addition of recycle streams and heat integration between disparate parts of the process. Most notably, the excess heat of the exothermic reaction was useful in lowering the energy required in the heater that powers the air and water coming into the SOEC. Furthermore, the heat of the reaction products were useful in getting the incoming reagents and recycled material up to the correct temperature in the reactor. The recycle stream was useful in increasing the conversion of our product from a single pass rate of ~15% to as high as 99% over extended periods of time. This benefit is mainly financial, as more product is undeniably best for the bottom line, but also environmental, as less energy would be going to waste in a higher conversion process.

14.3 Global, Social, and Cultural Factors

Generally, when designing a large-scale industrial process, it is important to consider how the construction and operation of said process will affect the world around you. In this process, the product that is output is ammonia, which is primarily used for fertilizer, but also as a refrigerant or as a reagent in polymer synthesis in fringe cases. This process has been utilized since the early 1900s, and is one of the earliest chemical synthesis processes. As a result, there is likely little to no concern regarding social and cultural clashes with this process, as there might be in the case of a new genetically modified food or product. Furthermore, there would potentially even be a positive cultural or social response given that a core value of our process is environmental safety. Many cultures and nations, like Norway, value respecting the environment, as can be seen by the investment of many nations in renewable energy sources. As such, it is reasonable to assume that this renewable ammonia synthesis process could be culturally and socially acceptable in most nations that we would be producing inside of, namely Norway.

The prime global factor that affects this process is the ammonia market. Due to the necessity of ammonia as a key component in fertilizer, it is incredibly unlikely that the demand for ammonia will decrease in the near future. In fact, unlike many markets, there are relatively few major European ammonia producers, meaning that a plant of the scale proposed here could reasonably expect to make a significant impact, especially if demand for cleanly produced ammonia increases, as it has for other products.

14.4 Safety

One of the defining characteristics of an ammonia processing plant is that great care must be taken to ensure that proper safety measures are taken into consideration- more so than many other plants of similar scale. This is due to the incredible pressures that the Haber-Bosch reaction is performed at. With pressures reaching upwards of 80 atmospheres, it is clear that if proper safety precautions are eschewed, then a catastrophe could potentially follow.

There are three most probable potential safety hazards that have been considered in this process design. The first is a fire or explosion caused by ignition of the hydrogen feed. The second is an explosion as a result of uncontrolled buildup of temperature and pressure inside of the reaction vessel. Finally, there is a toxic hazard if any liquid ammonia is released from inside of the synthesis loop. There are also smaller potential hazards regarding the storing and handling of liquid ammonia.

Another significant safety concern is as a result of hydrogen embrittlement of carbon. This concern is largely mitigated by material choice regarding the piping and vessels, which are made of alloys that are resistant to reaction with the hydrogen, but due to the potential dangers associated with this embrittlement, it is worth frequently assessing the piping to ensure there are no imperfections or cracks.

To ensure that a disaster does not occur, this process will be following the guidelines set forth in the AIChE Safety in Ammonia Plants and Related Facilities Symposium. The plant will utilize a HAZOP (hazards and operability) study with a team of expert process engineers, contractors, and outside safety consultants. Trip systems and strategies for safe shut down in case of emergency will also be developed.

14.5 Transportation

Transportation of the liquid ammonia product will be predominantly by rail cars and by river barges. Due to our location in Scandinavia, we will have a market that is accessible through landlocked transportation methods, but by utilizing the nearby ocean, we will be able to reach the larger European market.

The rail cars utilized will be outfitted with pressure vessels for anhydrous ammonia, with capacities in the range of 100-150 cubic meters of storage space. With this capacity, rail cars would need to come daily, with the latest possible delay in shipments being three days, as that is the capacity of the liquid ammonia storage vessels. This distribution method will be used mainly to provide our supply to smaller fertilizer processing facilities or other wholesale suppliers and merchants.

Transportation through larger ocean and river vessels will also be necessary to reach a larger market. Due to the large size of barges, which have larger capacities than even the most massive rail carts, much more liquid ammonia could be shipped. This solution would likely not be implemented in the first year that the plant is operational, as demand for the ammonia product would need to be sufficient to justify the extra storage vessels that would be required to make shipping the product by barge to be a profitable venture.

14.6 Plant Startup

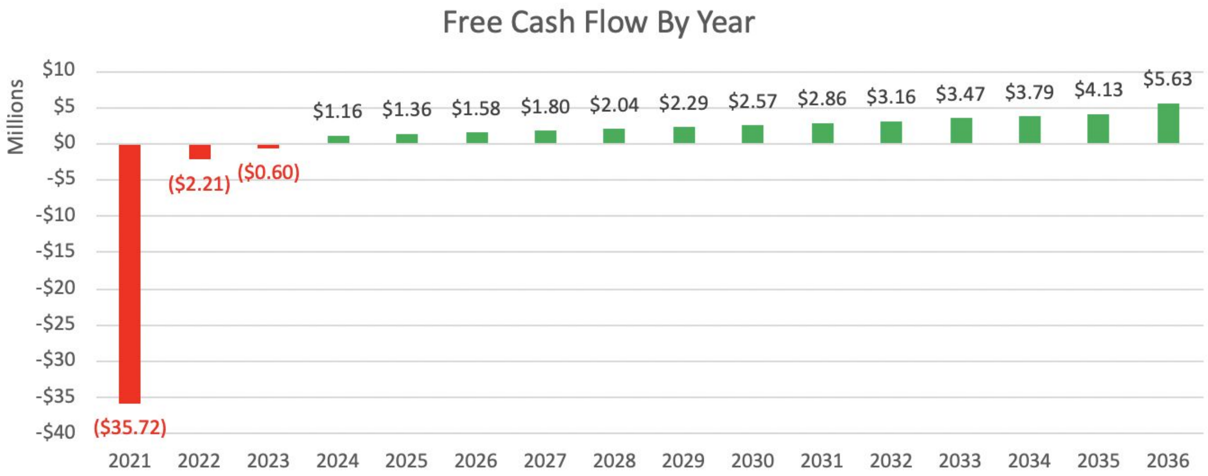
The design for this plant assumes that the cost of the reagents for the startup of the process is negligible, given that the only two inputs into the process are air and water, which are both available free of cost. The values given below describe the amount of these incoming reagents that are involved in the first "loop" through the process. The input into the first steps of the process are 203 kmol/hr of air and 563 kmol/hr of water. The air and water are separated into the desired constituents, which are 140 kmol/hr of nitrogen and 57 kmol/hr of hydrogen. Upon startup, either addition or regeneration of the iron catalyst that facilitates the Haber-Bosch reaction must be performed. Regeneration can be performed by drying the catalyst and heating to 300-400 degrees Celsius. A lifetime of six months is assumed for the iron catalyst. The total bare module cost, including this payment for catalyst is included in **Section 12.**.

15. Profitability Analysis

In sum, this project does not represent a profitable venture. Once investment is complete, our product yields annual positive cash flows, but the total upfront investment as it currently stands is simply too large for commercial viability.

The NPV of this proposal was currently calculated as USD -22M (discount rate of 10%). The project lifetime was modeled as 15 years, after construction was complete in 2021. Investment in year one was roughly ~USD 35M, so only one third of capital outlays were recuperated. Net present value was calculated by project cash flows in 2021-2036. Terminal valuation beyond 2036 was not factored into profitability. Assuming a discount rate of 10% and a FCF growth rate of 3%, using the Gordon Growth Model and valuing further profits as a perpetuity, a discounted terminal value of <$10M is attained. However, cashflows beyond this point would likely be hampered by additional capital expenditures.

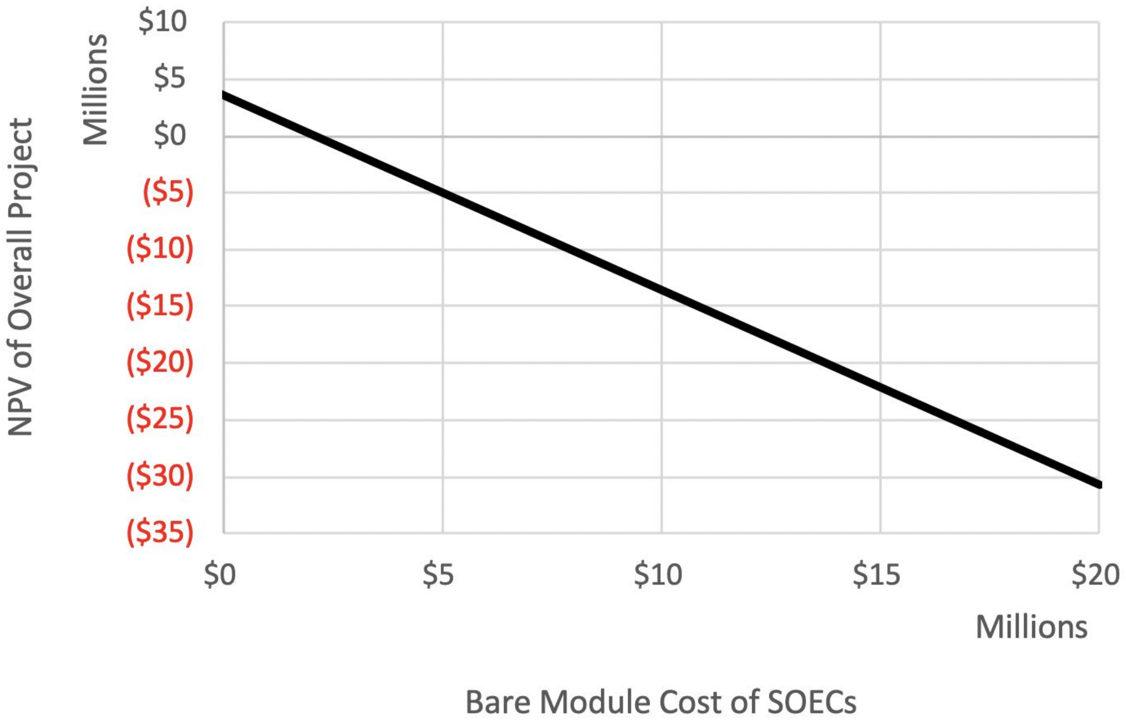
Figure 15.1a: Cash Flows



Using free cash flows, an internal rate of return of -0.68% was calculated. Neglecting the time value of money, this venture roughly repays initial outlays over the course of a 15 year lifetime.

The biggest obstacle to profitability is the cost of the SOEC, which represents ~60% of total permanent investment. If this price were to decrease from $15m to $2m, the project would become profitable. The SOEC is the most expensive unit purchased. Furthermore, few firms manufacture SOECs, and pricing information is hard to come by.

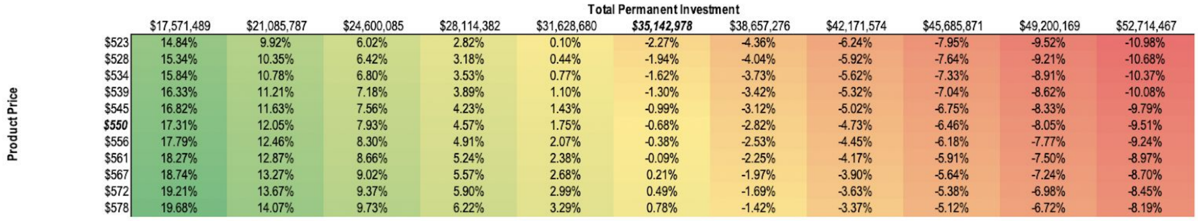
Figure 15.1b: NPV of overall project as a function of SOEC Bare Module Cost.



An additional consideration is the cost of ammonia. Ammonia's price is highly correlated to the price of oil. If oil prices were to increase, this venture would likely benefit.

The below table shows ROI as a bivariate function of total permanent investment and price per metric ton of ammonia. The venture would become largely profitable should SOEC prices decrease and a bull market for oil emerge.

Figure 15.1c: ROI as a function of Ammonia price and TPI.



	Total Permanent Investment										
Product Price	$17,571,489	$21,085,787	$24,600,085	$28,114,382	$31,628,680	***$35,142,978***	$38,657,276	$42,171,574	$45,685,871	$49,200,169	$52,714,467
$523	14.84%	9.92%	6.02%	2.82%	0.10%	-2.27%	-4.36%	-6.24%	-7.95%	-9.52%	-10.98%
$528	15.34%	10.35%	6.42%	3.18%	0.44%	-1.94%	-4.04%	-5.92%	-7.64%	-9.21%	-10.68%
$534	15.84%	10.78%	6.80%	3.53%	0.77%	-1.62%	-3.73%	-5.62%	-7.33%	-8.91%	-10.37%
$539	16.33%	11.21%	7.18%	3.89%	1.10%	-1.30%	-3.42%	-5.32%	-7.04%	-8.62%	-10.08%
$545	16.82%	11.63%	7.56%	4.23%	1.43%	-0.99%	-3.12%	-5.02%	-6.75%	-8.33%	-9.79%
$550	17.31%	12.05%	7.93%	4.57%	1.75%	-0.68%	-2.82%	-4.73%	-6.46%	-8.05%	-9.51%
$556	17.79%	12.46%	8.30%	4.91%	2.07%	-0.38%	-2.53%	-4.45%	-6.18%	-7.77%	-9.24%
$561	18.27%	12.87%	8.66%	5.24%	2.38%	-0.09%	-2.25%	-4.17%	-5.91%	-7.50%	-8.97%
$567	18.74%	13.27%	9.02%	5.57%	2.68%	0.21%	-1.97%	-3.90%	-5.64%	-7.24%	-8.70%
$572	19.21%	13.67%	9.37%	5.90%	2.99%	0.49%	-1.69%	-3.63%	-5.38%	-6.98%	-8.45%
$578	19.68%	14.07%	9.73%	6.22%	3.29%	0.78%	-1.42%	-3.37%	-5.12%	-6.72%	-8.19%

Another major factor preventing profitability are the large annual fixed costs. Because the plant is relatively small (annual revenue of ~$10m) and has so many operators (25), margins are relatively small. If the plant were to be expanded and could maintain the same number of operators and total maintenance expenses, the venture could become profitable. There are ammonia plants that manufacture well in excess of 50 times what this plant does. These plants do not have 50 times the manpower. By making use of economies of scale, it is possible that a fully green ammonia plant could be profitable in the future.

Further detailed calculations relating to profitability can be found in *Appendix D*.

16. Conclusions and Recommendations

With the effects of climate change growing more and more severe every year, it is hard to deny that green alternatives to current carbon-heavy processes would be of great use to the world, but as of this time it is difficult to make such ventures profitable. Unfortunately, we can not recommend that a plant with the given design be built, given that the profitability is currently negative. While after years of sustained operation the plant would turn a profit, the initial investment is currently too prohibitive to make the venture worthwhile. The cost of the purchased equipment is quite high because each of the main components of the plant must be made of expensive alloys, and is one of the most significant factors why the plant is unprofitable. The primary concern that has caused the profitability estimations to be so pessimistic is the cost of the reactor vessel and the cost of leasing the solid oxide electrolytic cells. Although the "free" energy that we would be able to obtain from wind power is a great boon, it is not enough to offset the massive cost of the electrolytic cells. Furthermore, the market for green ammonia is simply not profitable enough to overcome this deficit until the plant has operated for 15 years.

Though the process is not currently viable, it is reasonable to envision a future in which this exact process methodology would be usable in the coming years. Certain circumstances, such as the price of oil drastically increasing, a stark increase in tax for emissions, or a more lucrative green ammonia market, would enable our process to compete monetarily. A sensitivity analysis was performed to determine the degree to which altering these factors would allow us to overcome this barrier and to reach profitability sooner, and can be found in **Section 15**.

Despite the current lack of economic viability, this green ammonia process remains an interesting prospect given the benefits to society that could potentially be achieved if this process were a primary way that ammonia was produced and sold across the world. However, given the current landscape, further consideration should be made before action is undertaken to create a plant similar to the one outlined in this report.

17. Acknowledgements

We would like to thank Dr. Raymond Gorte, Professor Bruce Vrana, and Mr. Leonard Fabiano for their help throughout the project. In addition, we would like to thank the industrial consultants who met with us both in person and over Zoom. We would also like to thank the faculty in the University of Pennsylvania's Department of Chemical and Biomolecular Engineering.

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Appendix A: Manual Calculations

A.1 Hydrogen Production Calculations

To determine the extent of hydrogen able to be processed within the electrolyzer, a couple of assumptions were made: all the current will be used to electrolyze water, there are minimal to no voltage losses, the system is operating at its thermoneutral voltage. With these factors in mind, the calculation is as follows. For calculation purposes 1.285V was rounded to 1.3V.

Determining Current of the System

$$P = IV$$

$$I = \frac{P}{V}$$

$$I = \frac{500{,}000W}{1.3V}$$

$$I = 384{,}615 \ Amps\ per\ SOEC\ Stack$$

Determining moles of H_2 Produced

The reaction is as follows:

$$H_2O_{(g)} + 2\,e^{-} \ -> \ H_{2\,(g)} \ + \ O^{\,2-}$$

To determine mols of H_2 produced by the SOEC:

$$H_{2,\,produced} = \frac{I}{nF}$$

I = $current\ (amps)$

n = $mols\ of\ electrons$

F = $Faraday's\ Constant$

$$H_{2,\, produced} = \frac{384{,}615}{(2)(96485)} = 171200\ mols\ H_2 = 171.2\ kmols\ H_2$$

A.2 Calculation of Water Input

The removal of oxygen is primarily driven by its reaction with hydrogen. The reaction is as follows:

$$2H_{2\,(g)} + O_{2(g)} \text{–>} 2\, H_2O_{(g)} \qquad \Delta H_{rxn} = -247.2\ kJ/mol\ of\ rxn$$

As can be seen in the figure above, the oxyhydrogen reaction releases a significant amount of heat. Due to the operation of our SOEC stacks, the input must reach a temperature of 800°C prior to entry in order to maintain its thermoneutral operation at 1.285V. In addition, the temperature of the stream when it the hydrogen + air first mix must be high enough for this reaction to occur. The temperature at which this mixing occurs was taken to be about 600°C. Since water could be added to the process without raising the extent of the reaction, it was chosen to be the varying factor so that the process was able to absorb some of the excess heat produced by the reaction. This quantity was determined by the calculation detailed below.

Using coefficients from the NIST database, the specific heat values were determined using the Shomate Equation at 800°C for all of the components. It was assumed that the reaction took place at constant pressure.

Component	**C_p at 800°C (kJ/mol*K)**
H_2O	41.87
H_2	30.84
N_2	32.59
O_2	34.60

Ar	20.79

Assuming that all the oxygen reacted, the amount of heat released into the system was determined.

$$\Delta H_{rxn} = -247.2\ kJ/mol\ of\ rxn$$

$$\Delta H_{tot} = \Delta H_{rxn} * n_{o_2 reacted}$$

$$\Delta H_{tot} = 3,806,172.97\ kJ\ released/hr$$

To determine the amount of water that needed to be flowed through the system, the heat released was set equal to the specific heat formula of all the components. It is assumed that no heat was lost to the environment.

$$Q = \Delta H_{tot} = 3,806,172.97\ kJ/hr = \sum_{i=1}^{5} n_i C_{p,i} \Delta T$$

Since, all the other components had their molar flow rates set, we needed to solve for n_{H2O} which was determined to be 522.5 kmol/hr. Since 30.8 kmol/hr was formed, it was determined that the amount of water that needed to be fed into the system was 491.7 kmol/hr.

A.3 Calculation of Compression Ratios

Equations are taken from *Product and Process Design Principles* Chapter 16, Section 5, pg. 459-460

Sample calculation shown below:

Net Work Required = *PC* (*Hp*) = 1500 (From Aspen Block Results)

Electric compressor FD = 1 (From pg. 460)

Carbon steel material FM = 1 (From pg. 460)

FBM= 2.15 (From Table 16.11 on pg. 441)

According to Heuristic 36 on pg. 150, the compression ratio must be calculated to determine the number of stages.

Compression Ratio =*Outlet Pressure*/*Inlet Pressure* =1160.3 (psia)/580.15 (psia) = 2,

$2 < 3 \therefore$ *The number of gas compression stages is* 1.

A.4 Calculation of Storage Vessel Size

Time Capacity is the amount of time the material will be stored.

Assuming a safety factor of 2, the volume of the tank must be double the volume of the material stored throughout the specified amount of time.

Time Capacity = 3 days

235000

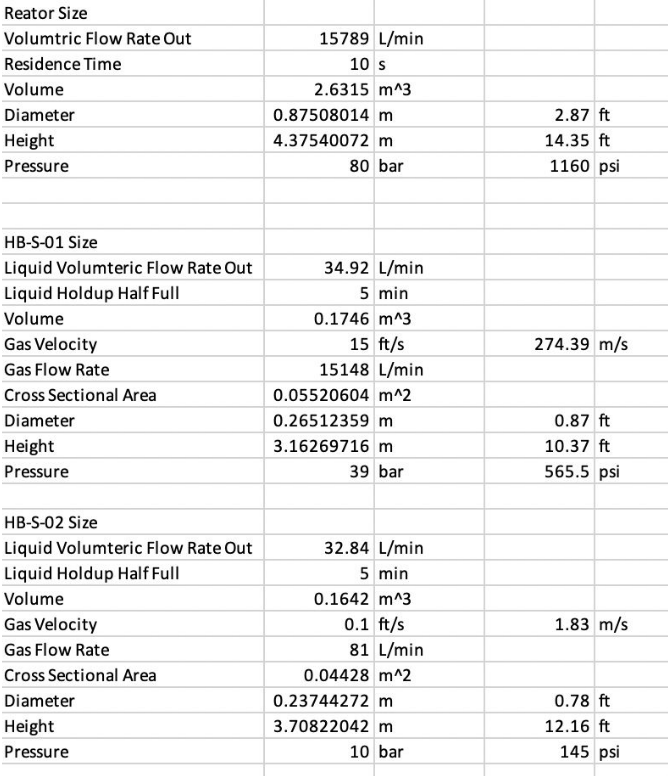
Volume of Tank = *Volumetric Flow Rate* ∗ *Time Capacity* ∗ *Safety Factor*

Tank volume =(333 gal/hr)*(0.134 ft^3/gal)*(24 hr/day)*(3 days) *(2) = 6,426 ft^3

$Diameter = D = (Volume\ of\ Tank/1.25 * \pi)^{1/3}$ = $(6{,}426/(1.25*\pi)^{1/3}$ = 11.8 f

Height = *L* = 2.5*D = 29.5 ft

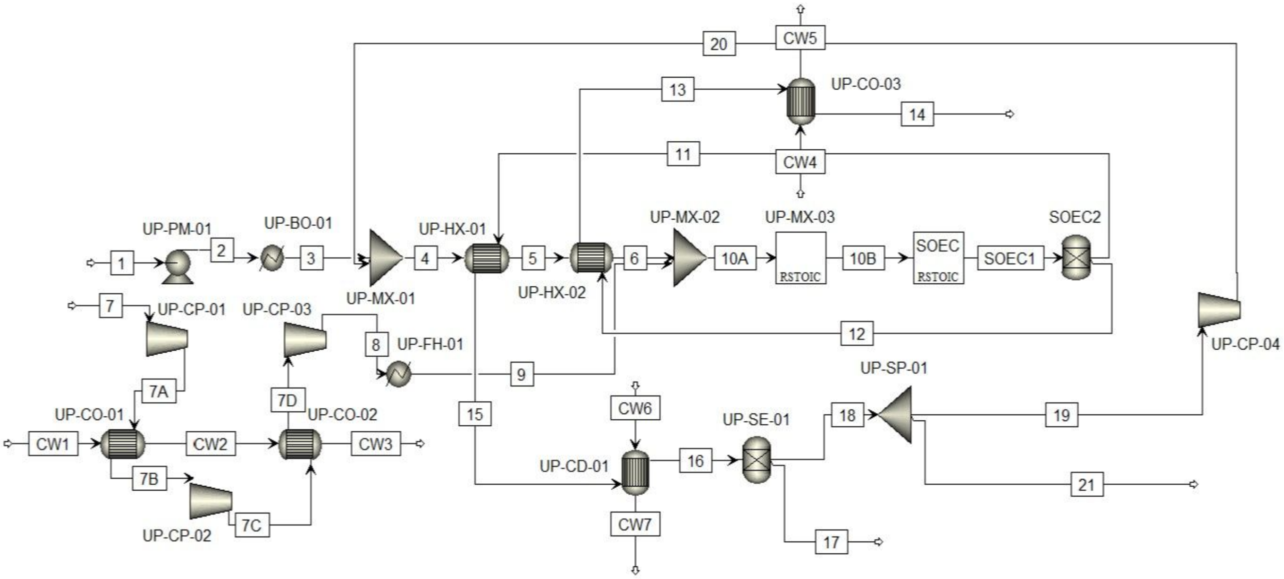
A.5 Calculation of Reactor, HB-S-01 and HB-S-02 Vessel Sizes



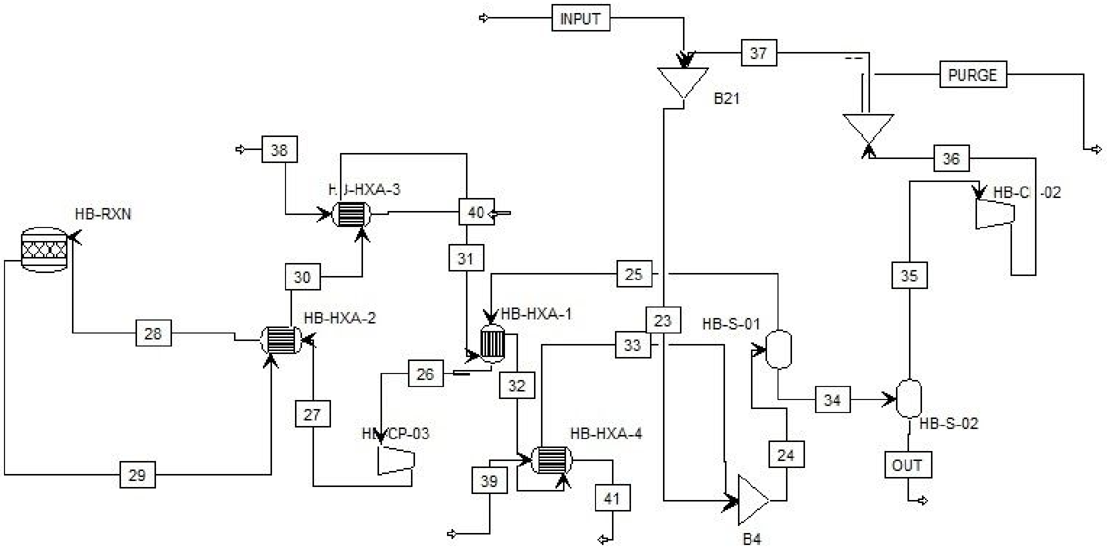
Reator Size				
Volumtric Flow Rate Out	15789	L/min		
Residence Time	10	s		
Volume	2.6315	m^3		
Diameter	0.87508014	m	2.87	ft
Height	4.37540072	m	14.35	ft
Pressure	80	bar	1160	psi
HB-S-01 Size				
Liquid Volumteric Flow Rate Out	34.92	L/min		
Liquid Holdup Half Full	5	min		
Volume	0.1746	m^3		
Gas Velocity	15	ft/s	274.39	m/s
Gas Flow Rate	15148	L/min		
Cross Sectional Area	0.05520604	m^2		
Diameter	0.26512359	m	0.87	ft
Height	3.16269716	m	10.37	ft
Pressure	39	bar	565.5	psi
HB-S-02 Size				
Liquid Volumteric Flow Rate Out	32.84	L/min		
Liquid Holdup Half Full	5	min		
Volume	0.1642	m^3		
Gas Velocity	0.1	ft/s	1.83	m/s
Gas Flow Rate	81	L/min		
Cross Sectional Area	0.04428	m^2		
Diameter	0.23744272	m	0.78	ft
Height	3.70822042	m	12.16	ft
Pressure	10	bar	145	psi

Appendix B: Aspen Flowsheet Information

B.1.1 SOEC System ASPEN Flow Diagram



B.2.1 Ammonia Synthesis ASPEN Flow Diagram



B.1.2 SOEC ASPEN Inputs

```
;
;Input Summary created by Aspen Plus Rel. 37.0 at 23:23:22 Sun Apr 19,
2020
;Directory \\nestor\jamekwon\SeniorDesignSOECv2_6  Filename
C:\Users\jamekwon\AppData\Local\Temp\~apcce4.txt
;


DYNAMICS
    DYNAMICS RESULTS=ON

IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm

DEF-STREAMS CONVEN ALL

MODEL-OPTION

DATABANKS 'APV110 PURE37' / 'APV110 AQUEOUS' / 'APV110 SOLIDS' &
         / 'APV110 INORGANIC' / 'APESV110 AP-EOS' /  &
        'NISTV110 NIST-TRC' / NOASPENPCD

PROP-SOURCES 'APV110 PURE37' / 'APV110 AQUEOUS' /  &
        'APV110 SOLIDS' / 'APV110 INORGANIC' / 'APESV110 AP-EOS' &
         / 'NISTV110 NIST-TRC'

COMPONENTS
    WATER H2O /
    HYDROGEN H2 /
    NITROGEN N2 /
    OXYGEN O2 /
    ARGON AR

SOLVE
    RUN-MODE MODE=SIM

FLOWSHEET
    BLOCK UP-PM-01 IN=1 OUT=2
    BLOCK UP-BO-01 IN=2 OUT=3
    BLOCK UP-FH-01 IN=8 OUT=9
    BLOCK UP-HX-01 IN=11 4 OUT=15 5
    BLOCK UP-HX-02 IN=12 5 OUT=13 6
    BLOCK SOEC IN=10B OUT=SOEC1
    BLOCK UP-MX-01 IN=3 20 OUT=4
    BLOCK UP-SE-01 IN=16 OUT=18 17
    BLOCK UP-SP-01 IN=18 OUT=19 21
    BLOCK UP-CP-04 IN=19 OUT=20
    BLOCK UP-MX-03 IN=10A OUT=10B
    BLOCK UP-MX-02 IN=6 9 OUT=10A
    BLOCK SOEC2 IN=SOEC1 OUT=11 12
    BLOCK UP-CP-01 IN=7 OUT=7A
    BLOCK UP-CO-01 IN=7A CW1 OUT=7B CW2
```

```
    BLOCK UP-CO-02 IN=7C CW2 OUT=7D CW3
    BLOCK UP-CP-02 IN=7B OUT=7C
    BLOCK UP-CP-03 IN=7D OUT=8
    BLOCK UP-CD-01 IN=15 CW6 OUT=16 CW7
    BLOCK UP-CO-03 IN=13 CW4 OUT=14 CW5

PROPERTIES SRK

STREAM 1
    SUBSTREAM MIXED TEMP=25. PRES=1. MOLE-FLOW=491.7
    MOLE-FLOW WATER 491.7

STREAM 2
    SUBSTREAM MIXED TEMP=25. PRES=40. MOLE-FLOW=522.5
    MOLE-FLOW WATER 522.5

STREAM 7
    SUBSTREAM MIXED TEMP=25. PRES=1. MOLE-FLOW=73.16
    MOLE-FLOW NITROGEN 57.1 / OXYGEN 15.4 / ARGON 0.66

STREAM 9
    SUBSTREAM MIXED TEMP=550. PRES=40. MOLE-FLOW=73.16  &
        FREE-WATER=NO NPHASE=2 PHASE=V
    MOLE-FLOW NITROGEN 57.1 / OXYGEN 15.4 / ARGON 0.66

STREAM 10B
    SUBSTREAM MIXED TEMP=800. PRES=39.3 FREE-WATER=NO NPHASE=1  &
        PHASE=V

STREAM 11
    SUBSTREAM MIXED TEMP=800. PRES=39.3

STREAM 12
    SUBSTREAM MIXED TEMP=800. PRES=39.3

STREAM CW1
    SUBSTREAM MIXED TEMP=80. <F> PRES=1. MOLE-FLOW=1000.
    MOLE-FLOW WATER 1000.

STREAM CW4
    SUBSTREAM MIXED TEMP=45. <F> PRES=1. MOLE-FLOW=1000.
    MOLE-FLOW WATER 1000.

STREAM CW6
    SUBSTREAM MIXED TEMP=0. <F> PRES=1. MOLE-FLOW=1000.
    MOLE-FLOW WATER 1000.

BLOCK UP-MX-01 MIXER
    PARAM PRES=40. NPHASE=1 PHASE=V
    BLOCK-OPTION FREE-WATER=NO

BLOCK UP-MX-02 MIXER
    PARAM
```

```
BLOCK UP-SP-01 FSPLIT
    FRAC 19 0.265

BLOCK SOEC2 SEP
    PARAM
    FRAC STREAM=12 SUBSTREAM=MIXED COMPS=WATER HYDROGEN  &
        NITROGEN ARGON FRACS=0. 0. 0. 0.
    MOLE-FLOW STREAM=12 SUBSTREAM=MIXED COMPS=OXYGEN FLOWS= &
        85.6

BLOCK UP-SE-01 SEP
    PARAM
    MOLE-FLOW STREAM=18 SUBSTREAM=MIXED COMPS=WATER HYDROGEN  &
        NITROGEN OXYGEN ARGON FLOWS=0. 232.8 77.6 0. 0.9
    FLASH-SPECS 18 PRES=38.9313 NPHASE=1 FREE-WATER=NO PHASE=V
    FLASH-SPECS 17 NPHASE=1 FREE-WATER=NO PHASE=L

BLOCK UP-BO-01 HEATER
    PARAM TEMP=420. PRES=40. DPPARMOPT=NO

BLOCK UP-FH-01 HEATER
    PARAM TEMP=550. PRES=40. NPHASE=1 PHASE=V DPPARMOPT=NO
    BLOCK-OPTION FREE-WATER=NO

BLOCK UP-CD-01 HEATX
    PARAM T-HOT=35. PRES-HOT=-0.5 <psi>
    FEEDS HOT=15 COLD=CW6
    OUTLETS-HOT 16
    OUTLETS-COLD CW7
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK UP-CO-01 HEATX
    PARAM T-HOT=100. <F> PRES-HOT=-0.3447
    FEEDS HOT=7A COLD=CW1
    OUTLETS-HOT 7B
    OUTLETS-COLD CW2
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK UP-CO-02 HEATX
    PARAM T-HOT=100. <F> PRES-HOT=-0.3447
    FEEDS HOT=7C COLD=CW2
    OUTLETS-HOT 7D
    OUTLETS-COLD CW3
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK UP-CO-03 HEATX
    PARAM T-HOT=35. PRES-HOT=-0.5 <psi>
    FEEDS HOT=13 COLD=CW4
```

```
    OUTLETS-HOT 14
    OUTLETS-COLD CW5
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK UP-HX-01 HEATX
    PARAM T-COLD=590. PRES-HOT=-5. <psi> PRES-COLD=-5. <psi>
    FEEDS HOT=11 COLD=4
    OUTLETS-HOT 15
    OUTLETS-COLD 5
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK UP-HX-02 HEATX
    PARAM T-COLD=610. PRES-HOT=-5. <psi> PRES-COLD=-5. <psi>
    FEEDS HOT=12 COLD=5
    OUTLETS-HOT 13
    OUTLETS-COLD 6
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK SOEC RSTOIC
    PARAM TEMP=800. PRES=39.3105 NPHASE=2
    STOIC 1 MIXED WATER -1. / HYDROGEN 1. / OXYGEN 0.5
    EXTENT 1 171.2
    BLOCK-OPTION FREE-WATER=NO

BLOCK UP-MX-03 RSTOIC
    PARAM TEMP=800. PRES=39.3105 NPHASE=1 PHASE=V
    STOIC 1 MIXED HYDROGEN -1. / OXYGEN -0.5 / WATER 1.
    EXTENT 1 30.8
    BLOCK-OPTION FREE-WATER=NO

BLOCK UP-PM-01 PUMP
    PARAM PRES=40.

BLOCK UP-CP-01 COMPR
    PARAM TYPE=ISENTROPIC PRES=3.42 SB-MAXIT=30 SB-TOL=0.0001

BLOCK UP-CP-02 COMPR
    PARAM TYPE=ISENTROPIC PRES=11.7 SB-MAXIT=30 SB-TOL=0.0001

BLOCK UP-CP-03 COMPR
    PARAM TYPE=ISENTROPIC PRES=40. SB-MAXIT=30 SB-TOL=0.0001

BLOCK UP-CP-04 COMPR
    PARAM TYPE=ISENTROPIC PRES=40. SB-MAXIT=30 SB-TOL=0.0001

DESIGN-SPEC CWSYS1
    DEFINE CW3T STREAM-VAR STREAM=CW3 SUBSTREAM=MIXED  &
        VARIABLE=TEMP UOM="F"
```

```
    SPEC "CW3T" TO "120"
    TOL-SPEC "0.0001"
    VARY MOLE-FLOW STREAM=CW1 SUBSTREAM=MIXED COMPONENT=WATER  &
        UOM="kmol/hr"
    LIMITS "400" "1000"

DESIGN-SPEC CWSYS2
    DEFINE CW5T STREAM-VAR STREAM=CW5 SUBSTREAM=MIXED  &
        VARIABLE=TEMP UOM="F"
    SPEC "CW5T" TO "85"
    TOL-SPEC "0.0001"
    VARY MOLE-FLOW STREAM=CW4 SUBSTREAM=MIXED COMPONENT=WATER  &
        UOM="kmol/hr"
    LIMITS "400" "50000"

DESIGN-SPEC CWSYS3
    DEFINE CW07T STREAM-VAR STREAM=CW7 SUBSTREAM=MIXED  &
        VARIABLE=TEMP UOM="F"
    SPEC "CW07T" TO "90"
    TOL-SPEC "0.001"
    VARY MOLE-FLOW STREAM=CW6 SUBSTREAM=MIXED COMPONENT=WATER  &
        UOM="kmol/hr"
    LIMITS "50" "500000"

EO-CONV-OPTI

STREAM-REPOR MOLEFLOW

PROPERTY-REP PCES
;
;
;
;
;
```

B.1.3 SOEC Full Summary

```
 + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + +
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 ASPEN PLUS IS A TRADEMARK OF           HOTLINE:
 ASPEN TECHNOLOGY, INC.                 U.S.A. 888/996-7100
 781/221-6400                           EUROPE (44) 1189-226555

 PLATFORM: WIN-X64                                       APRIL 19, 2020
 VERSION: 37.0   Build 395                               SUNDAY
 INSTALLATION:                                           11:21:21 P.M.
```

TABLE OF CONTENTS

TABLE OF CONTENTS

```
                              RUN CONTROL SECTION

 RUN CONTROL INFORMATION
 -----------------------

 THIS COPY OF ASPEN PLUS LICENSED TO UNIVERSITY OF PENNSYLVAN

 TYPE OF RUN: EDIT

 INPUT FILE NAME: _2402dax.inm

 INPUT PROBLEM DATA FILE NAME : _2402dax
 OUTPUT PROBLEM DATA FILE NAME: _2000dhp
 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\AspenTech\Aspen Plus V11.0\Engine\\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET
```

```
                               FLOWSHEET SECTION

 FLOWSHEET CONNECTIVITY BY STREAMS
 ---------------------------------

   STREAM     SOURCE     DEST           STREAM     SOURCE     DEST
   1          ----       UP-PM-01       7          ----       UP-CP-01
   CW1        ----       UP-CO-01       CW6        ----       UP-CD-01
   CW4        ----       UP-CO-03       2          UP-PM-01   UP-BO-01
   3          UP-BO-01   UP-MX-01       9          UP-FH-01   UP-MX-02
   15         UP-HX-01   UP-CD-01       5          UP-HX-01   UP-HX-02
   13         UP-HX-02   UP-CO-03       6          UP-HX-02   UP-MX-02
   SOEC1      SOEC       SOEC2          4          UP-MX-01   UP-HX-01
   18         UP-SE-01   UP-SP-01       17         UP-SE-01   ----
   19         UP-SP-01   UP-CP-04       21         UP-SP-01   ----
   20         UP-CP-04   UP-MX-01       10B        UP-MX-03   SOEC
   10A        UP-MX-02   UP-MX-03       11         SOEC2      UP-HX-01
   12         SOEC2      UP-HX-02       7A         UP-CP-01   UP-CO-01
   7B         UP-CO-01   UP-CP-02       CW2        UP-CO-01   UP-CO-02
   7D         UP-CO-02   UP-CP-03       CW3        UP-CO-02   ----
   7C         UP-CP-02   UP-CO-02       8          UP-CP-03   UP-FH-01
   16         UP-CD-01   UP-SE-01       CW7        UP-CD-01   ----
   14         UP-CO-03   ----           CW5        UP-CO-03   ----

 FLOWSHEET CONNECTIVITY BY BLOCKS
 --------------------------------

   BLOCK        INLETS                         OUTLETS
   UP-PM-01     1                              2
   UP-BO-01     2                              3
   UP-FH-01     8                              9
   UP-HX-01     11 4                           15 5
   UP-HX-02     12 5                           13 6
   SOEC         10B                            SOEC1
   UP-MX-01     3 20                           4
   UP-SE-01     16                             18 17
   UP-SP-01     18                             19 21
   UP-CP-04     19                             20
   UP-MX-03     10A                            10B
   UP-MX-02     6 9                            10A
   SOEC2        SOEC1                          11 12
   UP-CP-01     7                              7A
   UP-CO-01     7A CW1                         7B CW2
   UP-CO-02     7C CW2                         7D CW3
   UP-CP-02     7B                             7C
   UP-CP-03     7D                             8
   UP-CD-01     15 CW6                         16 CW7
   UP-CO-03     13 CW4                         14 CW5
```

```
                               FLOWSHEET SECTION

 CONVERGENCE STATUS SUMMARY
 --------------------------

   DESIGN-SPEC SUMMARY
   ===================


   DESIGN                                                                CONV
   SPEC      ERROR         TOLERANCE    ERR/TOL      VARIABLE   STAT
BLOCK
   ------    -----         ---------    -------      --------   ----  ----
-
   CWSYS1   -0.62375E-08  0.10000E-03 -0.62375E-04   403.02     #
$OLVER02
   CWSYS2   -0.16906E-04  0.10000E-03 -0.16906       889.66     #
$OLVER03
   CWSYS3   -0.23763E-06  0.10000E-02 -0.23763E-03   6392.4     #
$OLVER04

   TEAR STREAM SUMMARY
   ===================


   STREAM    VARIABLE         MAXIMUM      MAX. ERR.    ABSOLUTE
CONV
   ID        ID               ERR/TOL      RELATIVE     ERROR       STAT
BLOCK
   ------    --------         --------     -------      ---------   ----
-----
   15       ARGON MOLEFLOW    0.47370E-01  0.47370E-05  0.11816E-08  #
$OLVER01
   10B      WATER MOLEFLOW     0.0000       0.0000       0.0000      #
$OLVER01

   #  = CONVERGED
   *  = NOT CONVERGED
   LB = AT LOWER BOUNDS
   UB = AT UPPER BOUNDS

 DESIGN-SPEC:  CWSYS1
 --------------------

   SAMPLED VARIABLES:
     CW3T     : TEMPERATURE IN STREAM CW3 SUBSTREAM MIXED

   SPECIFICATION:
     MAKE CW3T APPROACH 120.000
     WITHIN          0.000100000
```

```
  MANIPULATED VARIABLES:
    VARY     : WATER MOLEFLOW IN STREAM CW1 SUBSTREAM MIXED
    LOWER LIMIT =        400.000                     KMOL/HR
    UPPER LIMIT =      1,000.00                      KMOL/HR
    FINAL VALUE =        403.018                     KMOL/HR

  VALUES OF ACCESSED FORTRAN VARIABLES:
    VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                     OF LOOP
    --------      --------------      -----------     -----
    CW3T            96.1141            120.000        F

DESIGN-SPEC:  CWSYS2
--------------------

  SAMPLED VARIABLES:
    CW5T     : TEMPERATURE IN STREAM CW5 SUBSTREAM MIXED
```

```
                               FLOWSHEET SECTION

 DESIGN-SPEC:  CWSYS2 (CONTINUED)

   SPECIFICATION:
     MAKE CW5T APPROACH 85.0000
     WITHIN          0.000100000

   MANIPULATED VARIABLES:
     VARY     : WATER MOLEFLOW IN STREAM CW4 SUBSTREAM MIXED
     LOWER LIMIT =         400.000                   KMOL/HR
     UPPER LIMIT =      50,000.0                     KMOL/HR
     FINAL VALUE =         889.656                   KMOL/HR

   VALUES OF ACCESSED FORTRAN VARIABLES:
     VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                      OF LOOP
     --------      --------------      -----------     -----
     CW5T            85.0000            85.0000        F

 DESIGN-SPEC:  CWSYS3
 --------------------

   SAMPLED VARIABLES:
     CW07T    : TEMPERATURE IN STREAM CW7 SUBSTREAM MIXED

   SPECIFICATION:
     MAKE CW07T APPROACH 90.0000
     WITHIN          0.00100000

   MANIPULATED VARIABLES:
     VARY     : WATER MOLEFLOW IN STREAM CW6 SUBSTREAM MIXED
     LOWER LIMIT =          50.0000                  KMOL/HR
     UPPER LIMIT =     500,000.                      KMOL/HR
     FINAL VALUE =       6,392.41                    KMOL/HR

   VALUES OF ACCESSED FORTRAN VARIABLES:
     VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                      OF LOOP
     --------      --------------      -----------     -----
     CW07T           90.0149            90.0000        F

 CONVERGENCE BLOCK:  $OLVER01
 ----------------------------
     Tear Stream  :  15         10B
     Tolerance used:  0.100D-03  0.100D-03
     Trace molefrac:  0.100D-05  0.100D-05

     MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
     QMAX =   0.0     QMIN =  -5.0
```

```
                              FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER01 (CONTINUED)
     METHOD: WEGSTEIN      STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:    20
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                         *** FINAL VALUES ***


     VAR#  TEAR STREAM VAR   STREAM    SUBSTREA COMPONEN UNIT
VALUE        PREV VALUE   ERR/TOL
     ----  ----------------  ------    -------- -------- ----         ---
--        ----------   -------
        1  TOTAL MOLEFLOW    15        MIXED             KMOL/HR
620.8822     620.8819    5.7749-03
        2  TOTAL MOLEFLOW    10B       MIXED             KMOL/HR
620.8822     620.8822       0.0
        3  MOLE-FLOW         15        MIXED    WATER    KMOL/HR
351.3000     351.3000       0.0
        4  MOLE-FLOW         15        MIXED    HYDROGEN KMOL/HR
191.0203     191.0199    1.8548-02
        5  MOLE-FLOW         15        MIXED    NITROGEN KMOL/HR
77.6640      77.6640       0.0
        6  MOLE-FLOW         15        MIXED    OXYGEN   KMOL/HR
0.0          0.0          0.0
        7  MOLE-FLOW         15        MIXED    ARGON    KMOL/HR
0.8980       0.8980    4.7370-02
        8  PRESSURE          15        MIXED             BAR
38.9658      38.9658       0.0
        9  MASS ENTHALPY     15        MIXED             CAL/GM       -
1958.3548   -1958.3552    2.1185-03
       10  MOLE-FLOW         10B       MIXED    WATER    KMOL/HR
522.5000     522.5000       0.0
       11  MOLE-FLOW         10B       MIXED    HYDROGEN KMOL/HR
19.8203      19.8203       0.0
       12  MOLE-FLOW         10B       MIXED    NITROGEN KMOL/HR
77.6640      77.6640       0.0
       13  MOLE-FLOW         10B       MIXED    OXYGEN   KMOL/HR
0.0          0.0          0.0
       14  MOLE-FLOW         10B       MIXED    ARGON    KMOL/HR
0.8980       0.8980       0.0
       15  PRESSURE          10B       MIXED             BAR
39.3105      39.3105       0.0
       16  MASS ENTHALPY     10B       MIXED             CAL/GM       -
2232.1863   -2232.1863       0.0

                         *** ITERATION HISTORY ***

     TEAR STREAMS AND TEAR VARIABLES:
```

```
     ITERATION MAX-ERR/TOL  VAR# STREAM ID VAR DESCRIPTION  SUBSTREA
COMPONEN ATTRIBUT ELEMENT
     --------- -----------  ---- --------- ---------------  -------- ----
---- -------- -------
          1      0.4737E-01    7 15        MOLE-FLO         MIXED
ARGON

 CONVERGENCE BLOCK:  $OLVER02
 ----------------------------
     SPECS: CWSYS1
     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:     7
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     0
```

```
                               FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER02 (CONTINUED)

                          *** FINAL VALUES ***


                     DESIGN SP
     VAR#  VAR NAME  CALCULATOR  VARIABLE DESCRIPTION       UNIT
VALUE          PREV VALUE     ERR/TOL
     ----  --------  ----------  --------------------       ----
-----          ----------     -------
        1  VARY      CWSYS1      CW1.MIXED.WATER.MOLEFLOW   KMOL/HR
403.0176       403.0208     -6.2375-05

                          *** ITERATION HISTORY ***

     DESIGN-SPEC ID: CWSYS1
     ITERATED:  WATER MOLEFLOW IN STREAM CW1 SUBSTREAM MIXED

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1      1000.     UB    -23.89        -0.2389E+06
          2      994.0           -23.79        -0.2379E+06
          3      400.0     LB    0.3019          3019.
          4      697.0           -16.88        -0.1688E+06
          5      404.0          -0.1003         -1003.
          6      403.0          -0.3183E-03     -3.183
          7      403.0          -0.6237E-08    -0.6237E-04

 CONVERGENCE BLOCK:  $OLVER03
 ----------------------------
     SPECS: CWSYS2
     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:    25
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     1

                          *** FINAL VALUES ***


                     DESIGN SP
     VAR#  VAR NAME  CALCULATOR  VARIABLE DESCRIPTION       UNIT
VALUE          PREV VALUE     ERR/TOL
     ----  --------  ----------  --------------------       ----
-----          ----------     -------
        1  VARY      CWSYS2      CW4.MIXED.WATER.MOLEFLOW   KMOL/HR
889.6555       889.6555        -0.1691
```

```
                    *** ITERATION HISTORY ***

DESIGN-SPEC ID: CWSYS2
ITERATED:  WATER MOLEFLOW IN STREAM CW4 SUBSTREAM MIXED

ITERATION  VARIABLE         ERROR          ERR/TOL
---------  --------         -----          -------
     1      889.7         -0.1691E-04    -0.1691
```

```
                               FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER04
 ----------------------------
     SPECS: CWSYS3
     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:    71
     NUMBER OF ITERATIONS ON LAST OUTER LOOP:     3

                          *** FINAL VALUES ***


                     DESIGN SP
     VAR#  VAR NAME  CALCULATOR  VARIABLE DESCRIPTION       UNIT
VALUE           PREV VALUE     ERR/TOL
     ----  --------  ----------  --------------------       ----
-----           ----------     -------
        1  VARY      CWSYS3      CW6.MIXED.WATER.MOLEFLOW   KMOL/HR
6392.4052       6392.5064     -2.3763-04

                          *** ITERATION HISTORY ***

     DESIGN-SPEC ID: CWSYS3
     ITERATED:  WATER MOLEFLOW IN STREAM CW6 SUBSTREAM MIXED

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1      6391.           0.1494E-01      14.94
          2      6393.          -0.1434E-02     -1.434
          3      6392.          -0.2376E-06    -0.2376E-03

 COMPUTATIONAL SEQUENCE
 ----------------------

 SEQUENCE USED WAS:
    UP-CP-01
    $OLVER02 UP-CO-01 UP-CP-02 UP-CO-02
    (RETURN $OLVER02)
    UP-CP-03 UP-FH-01 UP-PM-01 UP-BO-01
    $OLVER01 SOEC SOEC2
    |  $OLVER04 UP-CD-01
    |  (RETURN $OLVER04)
    |  *UP-SE-01 UP-SP-01 UP-CP-04 UP-MX-01 UP-HX-01 UP-HX-02 UP-MX-02
    |  UP-MX-03
    (RETURN $OLVER01)
    $OLVER03 UP-CO-03
    (RETURN $OLVER03)
```

```
OVERALL FLOWSHEET BALANCE
-------------------------
```

```
                              FLOWSHEET SECTION

 OVERALL FLOWSHEET BALANCE (CONTINUED)

                      ***  MASS AND ENERGY BALANCE  ***
                             IN           OUT       GENERATION   RELATIVE
DIFF.
   CONVENTIONAL COMPONENTS
           (KMOL/HR )
      WATER              8176.78       8036.38      -140.400
0.00000
      HYDROGEN           0.00000       140.400       140.400
0.252349E-05
      NITROGEN           57.1000       57.1000       0.00000
0.248877E-15
      OXYGEN             15.4000       85.6000       70.2000
0.166015E-15
      ARGON             0.660000      0.659996       0.00000
0.644485E-05
   TOTAL BALANCE
   MOLE(KMOL/HR )        8249.94       8320.14       70.2000
0.430943E-07
   MASS(KG/HR   )        149426.       149426.
0.591694E-08
   ENTHALPY(CAL/SEC )  -0.158378E+09 -0.153646E+09               -
0.298739E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

```
                          PHYSICAL PROPERTIES SECTION

 COMPONENTS
 ----------

  ID       TYPE  ALIAS          NAME
   WATER    C     H2O            WATER
   HYDROGEN C     H2             HYDROGEN
   NITROGEN C     N2             NITROGEN
   OXYGEN   C     O2             OXYGEN
   ARGON    C     AR             ARGON
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  SOEC     MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          10B
   OUTLET STREAM:         SOEC1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(KMOL/HR )         620.882       706.482       85.6000
0.00000
   MASS(KG/HR   )         11664.4       11664.4
0.00000
   ENTHALPY(CAL/SEC )   -0.723256E+07 -0.440427E+07               -
0.391050

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     WATER     -1.00    HYDROGEN   1.00    OXYGEN    0.500


   REACTION EXTENT SPECS: NUMBER=    1
     REACTION #   1: EXTENT=   171.2     KMOL/HR




   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE C                                  800.000
   SPECIFIED PRESSURE    BAR                                 39.3105
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO
```

```
                             U-O-S BLOCK SECTION

 BLOCK:  SOEC     MODEL: RSTOIC (CONTINUED)

                          ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                       800.00
   OUTLET PRESSURE       BAR                                     39.311
   HEAT DUTY             CAL/SEC                               0.28283E+07
   VAPOR FRACTION                                                1.0000



   V-L PHASE EQUILIBRIUM :

      COMP              F(I)          X(I)          Y(I)          K(I)
      WATER            0.49725       0.49725       0.49725
MISSING
      HYDROGEN         0.27038       0.27038       0.27038
MISSING
      NITROGEN         0.10993       0.10993       0.10993
MISSING
      OXYGEN           0.12116       0.12116       0.12116
MISSING
      ARGON            0.12710E-02   0.12710E-02   0.12710E-02
MISSING

 BLOCK:  SOEC2    MODEL: SEP
 ---------------------------
   INLET STREAM:          SOEC1
   OUTLET STREAMS:        11         12
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          706.482        706.482        0.00000
       MASS(KG/HR   )          11664.4        11664.4        0.00000
       ENTHALPY(CAL/SEC )    -0.440427E+07   -0.440460E+07
0.743308E-04

                  ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR
```

```
                             U-O-S BLOCK SECTION

 BLOCK:  SOEC2    MODEL: SEP (CONTINUED)


                          ***  INPUT DATA  ***

   FLASH SPECS FOR STREAM 11
   TWO    PHASE  TP  FLASH
   PRESSURE DROP         BAR                                   0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE                                       0.000100000

   FLASH SPECS FOR STREAM 12
   TWO    PHASE  TP  FLASH
   PRESSURE DROP         BAR                                   0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE                                       0.000100000

   FRACTION OF FEED
     SUBSTREAM= MIXED
       STREAM= 12        CPT= WATER     FRACTION=           0.0
                              HYDROGEN                      0.0
                              NITROGEN                      0.0
                              ARGON                         0.0

   MOLE-FLOW (KMOL/HR )
     SUBSTREAM= MIXED
       STREAM= 12        CPT= OXYGEN    FLOW=             85.6000


                           ***  RESULTS  ***

   HEAT DUTY             CAL/SEC                               -327.40

  COMPONENT = WATER
    STREAM     SUBSTREAM    SPLIT FRACTION
    11         MIXED                 1.00000

  COMPONENT = HYDROGEN
    STREAM     SUBSTREAM    SPLIT FRACTION
    11         MIXED                 1.00000

  COMPONENT = NITROGEN
    STREAM     SUBSTREAM    SPLIT FRACTION
    11         MIXED                 1.00000

  COMPONENT = OXYGEN
    STREAM     SUBSTREAM    SPLIT FRACTION
    12         MIXED                 1.00000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  SOEC2    MODEL: SEP (CONTINUED)

  COMPONENT = ARGON
    STREAM     SUBSTREAM    SPLIT FRACTION
    11         MIXED                1.00000

 BLOCK:  UP-BO-01 MODEL: HEATER
 ------------------------------
   INLET STREAM:          2
   OUTLET STREAM:         3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           491.700         491.700         0.00000
       MASS(KG/HR   )           8858.11         8858.11         0.00000
       ENTHALPY(CAL/SEC )     -0.941751E+07   -0.746901E+07   -0.206903

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                C                       420.000
   SPECIFIED PRESSURE                   BAR                      40.0000
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE
0.000100000



                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                     420.00
   OUTLET PRESSURE       BAR                                   40.000
   HEAT DUTY             CAL/SEC                             0.19485E+07
   OUTLET VAPOR FRACTION                                       1.0000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-BO-01 MODEL: HEATER (CONTINUED)

   V-L PHASE EQUILIBRIUM :

      COMP               F(I)           X(I)           Y(I)           K(I)
      WATER              1.0000         1.0000         1.0000
MISSING

 BLOCK:  UP-CD-01 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             15
   OUTLET STREAM:            16
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             CW6
   OUTLET STREAM:            CW7
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                IN               OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          7013.29         7013.29         0.00000
       MASS(KG/HR   )          124086.         124086.         0.00000
       ENTHALPY(CAL/SEC )    -0.128948E+09   -0.128948E+09   -
0.231119E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/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:  UP-CD-01 MODEL: HEATX (CONTINUED)

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE               C                       35.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.0345
     COLD SIDE PRESSURE DROP        BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   15        ----->|               HOT                  |-----> 16
   T=  5.9845D+02  |                                    |       T=
3.5000D+01
   P=  3.8966D+01  |                                    |       P=
3.8931D+01
   V=  1.0000D+00  |                                    |       V=
4.3473D-01
                   |                                    |
   CW7       <-----|               COLD                 |<----- CW6
   T=  3.2222D+01  |                                    |       T= -
1.7778D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC            1849243.1706
     CALCULATED (REQUIRED) AREA     SQM                     65.9652
     ACTUAL EXCHANGER AREA          SQM                     65.9652
```

```
  PER CENT OVER-DESIGN                                       0.0000

HEAT TRANSFER COEFFICIENT:
  AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K              0.0203
  UA (DIRTY)                     CAL/SEC-K               13392.1917

LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                     1.0000
  LMTD (CORRECTED)               C                         138.0837
  NUMBER OF SHELLS IN SERIES                               1

PRESSURE DROP:
  HOTSIDE, TOTAL                 BAR                         0.0345
  COLDSIDE, TOTAL                BAR                         0.0000
```

```
                           U-O-S BLOCK SECTION

 BLOCK:  UP-CD-01 MODEL: HEATX (CONTINUED)

                       ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                         HOT
         -------------------------------------------------------------
         |                             |                             |
 HOT IN  |             VAP             |             COND            |
HOT OUT
 ------> |                             |                             |---
--->
  598.5  |                        213.7|                             |
35.0
         |                             |                             |
 COLDOUT |             LIQ             |             LIQ             |
COLDIN
 <------ |                             |                             |<--
----
   32.2  |                         17.0|                             |  -
17.8
         |                             |                             |
         -------------------------------------------------------------
                                         COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     559364.539         7.8838     349.4788     0.0203
1600.5680
     2    1289878.632        58.0814     109.3894     0.0203
11791.6237
```

```
                             U-O-S BLOCK SECTION

HEATX COLD-TQCU UP-CD-01 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !     1.0000 !    32.2222 !     0.0    !
!  8.8059+04 !     1.0000 !    29.8281 !     0.0    !
!  1.7612+05 !     1.0000 !    27.4346 !     0.0    !
!  2.6418+05 !     1.0000 !    25.0420 !     0.0    !
!  3.5224+05 !     1.0000 !    22.6501 !     0.0    !
!------------+------------+------------+------------!
!  4.4030+05 !     1.0000 !    20.2593 !     0.0    !
!  5.2836+05 !     1.0000 !    17.8695 !     0.0    !
!  5.5935+05 !     1.0000 !    17.0286 !     0.0    !
!  6.1641+05 !     1.0000 !    15.4810 !     0.0    !
!  7.0447+05 !     1.0000 !    13.0937 !     0.0    !
!------------+------------+------------+------------!
!  7.9253+05 !     1.0000 !    10.7078 !     0.0    !
!  8.8059+05 !     1.0000 !     8.3234 !     0.0    !
!  9.6865+05 !     1.0000 !     5.9405 !     0.0    !
!  1.0567+06 !     1.0000 !     3.5594 !     0.0    !
!  1.1448+06 !     1.0000 !     1.1801 !     0.0    !
!------------+------------+------------+------------!
!  1.2328+06 !     1.0000 !    -1.1974 !     0.0    !
!  1.3209+06 !     1.0000 !    -3.5728 !     0.0    !
!  1.4089+06 !     1.0000 !    -5.9461 !     0.0    !
!  1.4970+06 !     1.0000 !    -8.3173 !     0.0    !
!  1.5851+06 !     1.0000 !   -10.6861 !     0.0    !
!------------+------------+------------+------------!
!  1.6731+06 !     1.0000 !   -13.0525 !     0.0    !
!  1.7612+06 !     1.0000 !   -15.4165 !     0.0    !
!  1.8492+06 !     1.0000 !   -17.7778 !     0.0    !
-----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR UP-CD-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    38.9658 !   598.4517 !     1.0000 !
 !  8.8059+04 !    38.9658 !   539.0362 !     1.0000 !
 !  1.7612+05 !    38.9658 !   478.9835 !     1.0000 !
 !  2.6418+05 !    38.9658 !   418.3820 !     1.0000 !
 !  3.5224+05 !    38.9658 !   357.3703 !     1.0000 !
 !------------+------------+------------+------------!
 !  4.4030+05 !    38.9658 !   296.1613 !     1.0000 !
 !  5.2836+05 !    38.9658 !   235.0891 !     1.0000 !
 !  5.5935+05 !    38.9658 !   213.7170 ! DEW>1.0000 !
 !  6.1641+05 !    38.9658 !   212.1274 !     0.9619 !
 !  7.0447+05 !    38.9658 !   209.3752 !     0.9040 !
 !------------+------------+------------+------------!
 !  7.9253+05 !    38.9658 !   206.1884 !     0.8472 !
 !  8.8059+05 !    38.9658 !   202.4636 !     0.7919 !
 !  9.6865+05 !    38.9658 !   198.0651 !     0.7382 !
 !  1.0567+06 !    38.9658 !   192.8126 !     0.6865 !
 !  1.1448+06 !    38.9658 !   186.4635 !     0.6375 !
 !------------+------------+------------+------------!
 !  1.2328+06 !    38.9658 !   178.6899 !     0.5917 !
 !  1.3209+06 !    38.9658 !   169.0453 !     0.5499 !
 !  1.4089+06 !    38.9658 !   156.9273 !     0.5131 !
 !  1.4970+06 !    38.9658 !   141.5472 !     0.4825 !
 !  1.5851+06 !    38.9658 !   121.9693 !     0.4594 !
 !------------+------------+------------+------------!
 !  1.6731+06 !    38.9658 !    97.3929 !     0.4445 !
 !  1.7612+06 !    38.9658 !    67.8882 !     0.4372 !
 !  1.8492+06 !    38.9658 !    34.9997 !     0.4347 !
 -----------------------------------------------------
```

```
                            U-O-S BLOCK SECTION

 BLOCK:  UP-CO-01 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             7A
   OUTLET STREAM:            7B
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             CW1
   OUTLET STREAM:            CW2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            476.178         476.178         0.00000
       MASS(KG/HR   )            9379.19         9379.19         0.00000
       ENTHALPY(CAL/SEC )      -0.769531E+07   -0.769531E+07     0.00000

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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                       37.7778
     LMTD CORRECTION FACTOR                                  1.00000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-01 MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.3447
     COLD SIDE PRESSURE DROP        BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   7A        ----->|               HOT                  |-----> 7B
   T=  1.9791D+02  |                                    |       T=
3.7778D+01
   P=  3.4200D+00  |                                    |       P=
3.0753D+00
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   CW2       <-----|               COLD                 |<----- CW1
   T=  3.6532D+01  |                                    |       T=
2.6667D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC              22875.9612
     CALCULATED (REQUIRED) AREA     SQM                      2.0065
     ACTUAL EXCHANGER AREA          SQM                      2.0065
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                     CAL/SEC-K              407.3491
```

```
LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                  1.0000
  LMTD (CORRECTED)               C                       56.1581
  NUMBER OF SHELLS IN SERIES                               1

PRESSURE DROP:
  HOTSIDE, TOTAL                 BAR                      0.3447
  COLDSIDE, TOTAL                BAR                      0.0000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-01 MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |                                                           |---
--->
  197.9  |                                                           |
37.8
         |                                                           |
 COLDOUT |                           LIQ                             |
COLDIN
 <------ |                                                           |<--
----
   36.5  |                                                           |
26.7
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      22875.961         2.0065      56.1581     0.0203
407.3491
```

```
                             U-O-S BLOCK SECTION

 HEATX COLD-TQCU UP-CO-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0          BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     1.0000 !    36.5319 !     0.0    !
 !  1089.3315 !     1.0000 !    36.0619 !     0.0    !
 !  2178.6630 !     1.0000 !    35.5919 !     0.0    !
 !  3267.9945 !     1.0000 !    35.1220 !     0.0    !
 !  4357.3259 !     1.0000 !    34.6521 !     0.0    !
 !------------+------------+------------+------------!
 !  5446.6574 !     1.0000 !    34.1822 !     0.0    !
 !  6535.9889 !     1.0000 !    33.7123 !     0.0    !
 !  7625.3204 !     1.0000 !    33.2424 !     0.0    !
 !  8714.6519 !     1.0000 !    32.7725 !     0.0    !
 !  9803.9834 !     1.0000 !    32.3027 !     0.0    !
 !------------+------------+------------+------------!
 !  1.0893+04 !     1.0000 !    31.8329 !     0.0    !
 !  1.1983+04 !     1.0000 !    31.3631 !     0.0    !
 !  1.3072+04 !     1.0000 !    30.8934 !     0.0    !
 !  1.4161+04 !     1.0000 !    30.4236 !     0.0    !
 !  1.5251+04 !     1.0000 !    29.9539 !     0.0    !
 !------------+------------+------------+------------!
 !  1.6340+04 !     1.0000 !    29.4842 !     0.0    !
 !  1.7429+04 !     1.0000 !    29.0146 !     0.0    !
 !  1.8519+04 !     1.0000 !    28.5449 !     0.0    !
 !  1.9608+04 !     1.0000 !    28.0753 !     0.0    !
 !  2.0697+04 !     1.0000 !    27.6057 !     0.0    !
 !------------+------------+------------+------------!
 !  2.1787+04 !     1.0000 !    27.1362 !     0.0    !
 !  2.2876+04 !     1.0000 !    26.6667 !     0.0    !
 -----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR UP-CO-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     3.4200 !   197.9118 !     1.0000 !
 !  1089.3315 !     3.4200 !   190.3568 !     1.0000 !
 !  2178.6630 !     3.4200 !   182.7929 !     1.0000 !
 !  3267.9945 !     3.4200 !   175.2203 !     1.0000 !
 !  4357.3259 !     3.4200 !   167.6394 !     1.0000 !
 !------------+------------+------------+------------!
 !  5446.6574 !     3.4200 !   160.0505 !     1.0000 !
 !  6535.9889 !     3.4200 !   152.4540 !     1.0000 !
 !  7625.3204 !     3.4200 !   144.8500 !     1.0000 !
 !  8714.6519 !     3.4200 !   137.2391 !     1.0000 !
 !  9803.9834 !     3.4200 !   129.6216 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.0893+04 !     3.4200 !   121.9979 !     1.0000 !
 !  1.1983+04 !     3.4200 !   114.3684 !     1.0000 !
 !  1.3072+04 !     3.4200 !   106.7334 !     1.0000 !
 !  1.4161+04 !     3.4200 !    99.0935 !     1.0000 !
 !  1.5251+04 !     3.4200 !    91.4489 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.6340+04 !     3.4200 !    83.8003 !     1.0000 !
 !  1.7429+04 !     3.4200 !    76.1480 !     1.0000 !
 !  1.8519+04 !     3.4200 !    68.4925 !     1.0000 !
 !  1.9608+04 !     3.4200 !    60.8342 !     1.0000 !
 !  2.0697+04 !     3.4200 !    53.1737 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.1787+04 !     3.4200 !    45.5114 !     1.0000 !
 !  2.2876+04 !     3.4200 !    37.8479 !     1.0000 !
 -----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-02 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             7C
   OUTLET STREAM:            7D
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             CW2
   OUTLET STREAM:            CW3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           476.178         476.178         0.00000
       MASS(KG/HR   )           9379.19         9379.19         0.00000
       ENTHALPY(CAL/SEC )      -0.766691E+07   -0.766691E+07
0.121473E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/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                         37.7778
     LMTD CORRECTION FACTOR                                   1.00000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-02 MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.3447
     COLD SIDE PRESSURE DROP        BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   7C        ----->|                HOT                 |-----> 7D
   T=  2.3622D+02  |                                    |       T=
3.7778D+01
   P=  1.1700D+01  |                                    |       P=
1.1355D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   CW3       <-----|                COLD                |<----- CW2
   T=  4.8889D+01  |                                    |       T=
3.6532D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC              28635.0522
     CALCULATED (REQUIRED) AREA     SQM                      3.7997
     ACTUAL EXCHANGER AREA          SQM                      3.7997
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                     CAL/SEC-K              771.4194
```

```
LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                  1.0000
  LMTD (CORRECTED)               C                       37.1200
  NUMBER OF SHELLS IN SERIES                               1

PRESSURE DROP:
  HOTSIDE, TOTAL                 BAR                      0.3447
  COLDSIDE, TOTAL                BAR                      0.0000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-02 MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                         HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |                                                           |---
--->
  236.2  |                                                           |
37.8
         |                                                           |
 COLDOUT |                           LIQ                             |
COLDIN
 <------ |                                                           |<--
----
   48.9  |                                                           |
36.5
         |                                                           |
         -------------------------------------------------------------
                                         COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      28635.052         3.7997      37.1200     0.0203
771.4194
```

```
                               U-O-S BLOCK SECTION

 HEATX COLD-TQCU UP-CO-02 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     1.0000 !    48.8889 !     0.0    !
 !  1363.5739 !     1.0000 !    48.3004 !     0.0    !
 !  2727.1478 !     1.0000 !    47.7120 !     0.0    !
 !  4090.7217 !     1.0000 !    47.1235 !     0.0    !
 !  5454.2957 !     1.0000 !    46.5351 !     0.0    !
 !------------+------------+------------+------------!
 !  6817.8696 !     1.0000 !    45.9466 !     0.0    !
 !  8181.4435 !     1.0000 !    45.3581 !     0.0    !
 !  9545.0174 !     1.0000 !    44.7696 !     0.0    !
 !  1.0909+04 !     1.0000 !    44.1812 !     0.0    !
 !  1.2272+04 !     1.0000 !    43.5927 !     0.0    !
 !------------+------------+------------+------------!
 !  1.3636+04 !     1.0000 !    43.0042 !     0.0    !
 !  1.4999+04 !     1.0000 !    42.4158 !     0.0    !
 !  1.6363+04 !     1.0000 !    41.8273 !     0.0    !
 !  1.7726+04 !     1.0000 !    41.2389 !     0.0    !
 !  1.9090+04 !     1.0000 !    40.6505 !     0.0    !
 !------------+------------+------------+------------!
 !  2.0454+04 !     1.0000 !    40.0620 !     0.0    !
 !  2.1817+04 !     1.0000 !    39.4736 !     0.0    !
 !  2.3181+04 !     1.0000 !    38.8853 !     0.0    !
 !  2.4544+04 !     1.0000 !    38.2969 !     0.0    !
 !  2.5908+04 !     1.0000 !    37.7085 !     0.0    !
 !------------+------------+------------+------------!
 !  2.7271+04 !     1.0000 !    37.1202 !     0.0    !
 !  2.8635+04 !     1.0000 !    36.5319 !     0.0    !
 -----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR UP-CO-02 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    11.7000 !   236.2172 !     1.0000 !
 !  1363.5739 !    11.7000 !   226.8587 !     1.0000 !
 !  2727.1478 !    11.7000 !   217.4864 !     1.0000 !
 !  4090.7217 !    11.7000 !   208.1009 !     1.0000 !
 !  5454.2957 !    11.7000 !   198.7028 !     1.0000 !
 !------------+------------+------------+------------!
 !  6817.8696 !    11.7000 !   189.2927 !     1.0000 !
 !  8181.4435 !    11.7000 !   179.8714 !     1.0000 !
 !  9545.0174 !    11.7000 !   170.4396 !     1.0000 !
 !  1.0909+04 !    11.7000 !   160.9980 !     1.0000 !
 !  1.2272+04 !    11.7000 !   151.5476 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.3636+04 !    11.7000 !   142.0893 !     1.0000 !
 !  1.4999+04 !    11.7000 !   132.6240 !     1.0000 !
 !  1.6363+04 !    11.7000 !   123.1527 !     1.0000 !
 !  1.7726+04 !    11.7000 !   113.6767 !     1.0000 !
 !  1.9090+04 !    11.7000 !   104.1968 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.0454+04 !    11.7000 !    94.7145 !     1.0000 !
 !  2.1817+04 !    11.7000 !    85.2310 !     1.0000 !
 !  2.3181+04 !    11.7000 !    75.7476 !     1.0000 !
 !  2.4544+04 !    11.7000 !    66.2658 !     1.0000 !
 !  2.5908+04 !    11.7000 !    56.7871 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.7271+04 !    11.7000 !    47.3130 !     1.0000 !
 !  2.8635+04 !    11.7000 !    37.8454 !     1.0000 !
 -----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-03 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             13
   OUTLET STREAM:            14
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             CW4
   OUTLET STREAM:            CW5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT          RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            975.256         975.256         0.00000
       MASS(KG/HR   )            18766.5         18766.5         0.00000
       ENTHALPY(CAL/SEC )      -0.170273E+08   -0.170273E+08     0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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                       35.0000
     LMTD CORRECTION FACTOR                                  1.00000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-03 MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.0345
     COLD SIDE PRESSURE DROP        BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   13        ----->|               HOT                  |-----> 14
   T=  6.4962D+02  |                                    |       T=
3.5000D+01
   P=  3.8966D+01  |                                    |       P=
3.8931D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   CW5       <-----|               COLD                 |<----- CW4
   T=  2.9444D+01  |                                    |       T=
7.2222D+00
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC             113997.9145
     CALCULATED (REQUIRED) AREA     SQM                      2.9438
     ACTUAL EXCHANGER AREA          SQM                      2.9438
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                     CAL/SEC-K              597.6554
```

```
LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                      1.0000
  LMTD (CORRECTED)              C                           190.7419
  NUMBER OF SHELLS IN SERIES                                  1

PRESSURE DROP:
  HOTSIDE, TOTAL                BAR                           0.0345
  COLDSIDE, TOTAL               BAR                           0.0000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CO-03 MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |                                                           |---
--->
  649.6  |                                                           |
35.0
         |                                                           |
 COLDOUT |                           LIQ                             |
COLDIN
 <------ |                                                           |<--
----
   29.4  |                                                           |
7.2
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1    113997.915        2.9438     190.7419     0.0203
597.6554
```

```
                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU UP-CO-03 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0          BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     1.0000 !    29.4444 !     0.0    !
 !  5428.4721 !     1.0000 !    28.3842 !     0.0    !
 !  1.0857+04 !     1.0000 !    27.3242 !     0.0    !
 !  1.6285+04 !     1.0000 !    26.2643 !     0.0    !
 !  2.1714+04 !     1.0000 !    25.2045 !     0.0    !
 !------------+------------+------------+------------!
 !  2.7142+04 !     1.0000 !    24.1450 !     0.0    !
 !  3.2571+04 !     1.0000 !    23.0856 !     0.0    !
 !  3.7999+04 !     1.0000 !    22.0264 !     0.0    !
 !  4.3428+04 !     1.0000 !    20.9674 !     0.0    !
 !  4.8856+04 !     1.0000 !    19.9086 !     0.0    !
 !------------+------------+------------+------------!
 !  5.4285+04 !     1.0000 !    18.8500 !     0.0    !
 !  5.9713+04 !     1.0000 !    17.7916 !     0.0    !
 !  6.5142+04 !     1.0000 !    16.7335 !     0.0    !
 !  7.0570+04 !     1.0000 !    15.6756 !     0.0    !
 !  7.5999+04 !     1.0000 !    14.6179 !     0.0    !
 !------------+------------+------------+------------!
 !  8.1427+04 !     1.0000 !    13.5606 !     0.0    !
 !  8.6856+04 !     1.0000 !    12.5034 !     0.0    !
 !  9.2284+04 !     1.0000 !    11.4466 !     0.0    !
 !  9.7712+04 !     1.0000 !    10.3901 !     0.0    !
 !  1.0314+05 !     1.0000 !     9.3338 !     0.0    !
 !------------+------------+------------+------------!
 !  1.0857+05 !     1.0000 !     8.2779 !     0.0    !
 !  1.1400+05 !     1.0000 !     7.2222 !     0.0    !
 -----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR UP-CO-03 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0          BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    38.9658 !   649.6228 !     1.0000 !
 !  5428.4721 !    38.9658 !   621.9434 !     1.0000 !
 !  1.0857+04 !    38.9658 !   594.1472 !     1.0000 !
 !  1.6285+04 !    38.9658 !   566.2272 !     1.0000 !
 !  2.1714+04 !    38.9658 !   538.1757 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.7142+04 !    38.9658 !   509.9844 !     1.0000 !
 !  3.2571+04 !    38.9658 !   481.6443 !     1.0000 !
 !  3.7999+04 !    38.9658 !   453.1458 !     1.0000 !
 !  4.3428+04 !    38.9658 !   424.4788 !     1.0000 !
 !  4.8856+04 !    38.9658 !   395.6328 !     1.0000 !
 !------------+------------+------------+------------!
 !  5.4285+04 !    38.9658 !   366.5973 !     1.0000 !
 !  5.9713+04 !    38.9658 !   337.3621 !     1.0000 !
 !  6.5142+04 !    38.9658 !   307.9180 !     1.0000 !
 !  7.0570+04 !    38.9658 !   278.2580 !     1.0000 !
 !  7.5999+04 !    38.9658 !   248.3788 !     1.0000 !
 !------------+------------+------------+------------!
 !  8.1427+04 !    38.9658 !   218.2828 !     1.0000 !
 !  8.6856+04 !    38.9658 !   187.9816 !     1.0000 !
 !  9.2284+04 !    38.9658 !   157.4991 !     1.0000 !
 !  9.7712+04 !    38.9658 !   126.8775 !     1.0000 !
 !  1.0314+05 !    38.9658 !    96.1829 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.0857+05 !    38.9658 !    65.5132 !     1.0000 !
 !  1.1400+05 !    38.9658 !    35.0080 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  UP-CP-01 MODEL: COMPR
 -----------------------------
   INLET STREAM:          7
   OUTLET STREAM:         7A
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                           ***  MASS AND ENERGY BALANCE  ***
```

IN OUT RELATIVE DIFF.

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CP-01 MODEL: COMPR (CONTINUED)
    TOTAL BALANCE
       MOLE(KMOL/HR )            73.1600         73.1600         0.00000
       MASS(KG/HR   )            2118.72         2118.72         0.00000
       ENTHALPY(CAL/SEC )       -32.2948         24591.9        -1.00131

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                     3.42000
    ISENTROPIC EFFICIENCY                                    0.72000
    MECHANICAL EFFICIENCY                                    1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                  103.097
    BRAKE      HORSEPOWER REQUIREMENT  KW                  103.097
    NET WORK REQUIRED                  KW                  103.097
    POWER LOSSES                       KW                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                   74.2295
    CALCULATED OUTLET TEMP  C                              197.912
    ISENTROPIC TEMPERATURE  C                              149.950
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       M-KGF/KG                      12,861.3
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.40242
    INLET VOLUMETRIC FLOW RATE , L/MIN                  30,221.5
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                  13,983.5
    INLET  COMPRESSIBILITY FACTOR                            0.99984
    OUTLET COMPRESSIBILITY FACTOR                            1.00141
    AV. ISENT. VOL. EXPONENT                                 1.40015
    AV. ISENT. TEMP EXPONENT                                 1.39791
    AV. ACTUAL VOL. EXPONENT                                 1.59553
    AV. ACTUAL TEMP EXPONENT                                 1.59229
```

```
                               U-O-S BLOCK SECTION

 BLOCK:  UP-CP-02 MODEL: COMPR
 -----------------------------
   INLET STREAM:          7B
   OUTLET STREAM:         7C
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           73.1600         73.1600         0.00000
       MASS(KG/HR   )           2118.72         2118.72         0.00000
       ENTHALPY(CAL/SEC )       1715.93         30114.2       -0.943019

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                     11.7000
    ISENTROPIC EFFICIENCY                                     0.72000
    MECHANICAL EFFICIENCY                                     1.00000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CP-02 MODEL: COMPR (CONTINUED)

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                  118.898
    BRAKE      HORSEPOWER REQUIREMENT  KW                  118.898
    NET WORK REQUIRED                  KW                  118.898
    POWER LOSSES                       KW                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                   85.6064
    CALCULATED OUTLET TEMP  C                              236.217
    ISENTROPIC TEMPERATURE  C                              181.461
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       M-KGF/KG                      14,832.5
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.40517
    INLET VOLUMETRIC FLOW RATE , L/MIN                  10,248.4
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                   4,435.97
    INLET  COMPRESSIBILITY FACTOR                            0.99985
    OUTLET COMPRESSIBILITY FACTOR                            1.00506
    AV. ISENT. VOL. EXPONENT                                 1.40440
    AV. ISENT. TEMP EXPONENT                                 1.39724
    AV. ACTUAL VOL. EXPONENT                                 1.59568
    AV. ACTUAL TEMP EXPONENT                                 1.58583

 BLOCK:  UP-CP-03 MODEL: COMPR
 -----------------------------
   INLET STREAM:          7D
   OUTLET STREAM:         8
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            73.1600         73.1600         0.00000
       MASS(KG/HR   )            2118.72         2118.72         0.00000
       ENTHALPY(CAL/SEC )        1479.11         28087.9       -0.947340

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CP-03 MODEL: COMPR (CONTINUED)

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                    40.0000
    ISENTROPIC EFFICIENCY                                    0.72000
    MECHANICAL EFFICIENCY                                    1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                  111.405
    BRAKE      HORSEPOWER REQUIREMENT  KW                  111.405
    NET WORK REQUIRED                  KW                  111.405
    POWER LOSSES                       KW                   0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                   80.2120
    CALCULATED OUTLET TEMP  C                              222.905
    ISENTROPIC TEMPERATURE  C                              172.329
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       M-KGF/KG                      13,897.9
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.41832
    INLET VOLUMETRIC FLOW RATE , L/MIN                   2,774.96
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                   1,279.26
    INLET  COMPRESSIBILITY FACTOR                            0.99965
    OUTLET COMPRESSIBILITY FACTOR                            1.01751
    AV. ISENT. VOL. EXPONENT                                 1.42616
    AV. ISENT. TEMP EXPONENT                                 1.39972
    AV. ACTUAL VOL. EXPONENT                                 1.62612
    AV. ACTUAL TEMP EXPONENT                                 1.58976

 BLOCK:  UP-CP-04 MODEL: COMPR
 -----------------------------
   INLET STREAM:          19
   OUTLET STREAM:         20
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

```
                                U-O-S BLOCK SECTION

 BLOCK:  UP-CP-04 MODEL: COMPR (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          71.4222         71.4222          0.00000
       MASS(KG/HR   )          687.620         687.620       -
0.165334E-15
       ENTHALPY(CAL/SEC )      1372.66         1840.32       -0.254120

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                     40.0000
    ISENTROPIC EFFICIENCY                                     0.72000
    MECHANICAL EFFICIENCY                                     1.00000

                          ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                     1.95801
    BRAKE      HORSEPOWER REQUIREMENT  KW                     1.95801
    NET WORK REQUIRED                  KW                     1.95801
    POWER LOSSES                       KW                     0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                     1.40977
    CALCULATED OUTLET TEMP  C                                38.3557
    ISENTROPIC TEMPERATURE  C                                37.4150
    EFFICIENCY (POLYTR/ISENTR) USED                           0.72000
    OUTLET VAPOR FRACTION                                     1.00000
    HEAD DEVELOPED,       M-KGF/KG                          752.630
    MECHANICAL EFFICIENCY USED                                1.00000
    INLET HEAT CAPACITY RATIO                                 1.41657
    INLET VOLUMETRIC FLOW RATE , L/MIN                      798.958
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                      786.496
    INLET  COMPRESSIBILITY FACTOR                             1.01989
    OUTLET COMPRESSIBILITY FACTOR                             1.02043
    AV. ISENT. VOL. EXPONENT                                  1.44519
    AV. ISENT. TEMP EXPONENT                                  1.40503
    AV. ACTUAL VOL. EXPONENT                                  1.72261
    AV. ACTUAL TEMP EXPONENT                                  1.66651
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-CP-04 MODEL: COMPR (CONTINUED)

 BLOCK:  UP-FH-01 MODEL: HEATER
 ------------------------------
   INLET STREAM:          8
   OUTLET STREAM:         9
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            73.1600         73.1600          0.00000
       MASS(KG/HR   )            2118.72         2118.72          0.00000
       ENTHALPY(CAL/SEC )        28087.9         77585.2        -0.637974

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED TEMPERATURE                C                       550.000
   SPECIFIED PRESSURE                   BAR                      40.0000
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE
0.000100000



                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                    550.00
   OUTLET PRESSURE       BAR                                  40.000
   HEAT DUTY             CAL/SEC                              49497.
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-HX-01 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             11
   OUTLET STREAM:            15
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             4
   OUTLET STREAM:            5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            1184.00         1184.00         0.00000
       MASS(KG/HR   )            18471.1         18471.1         0.00000
       ENTHALPY(CAL/SEC )      -0.120156E+08   -0.120156E+08   -
0.155019E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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 OUTLET TEMP
     SPECIFIED VALUE               C                        590.0000
     LMTD CORRECTION FACTOR                                   1.00000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-HX-01 MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                          0.3447
     COLD SIDE PRESSURE DROP        BAR                          0.3447

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K               0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K               0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K               0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K               0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K               0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K               0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K               0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K               0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K               0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   11        ----->|                HOT                 |-----> 15
   T=  8.0000D+02  |                                    |       T=
5.9845D+02
   P=  3.9311D+01  |                                    |       P=
3.8966D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   5         <-----|                COLD                |<----- 4
   T=  5.9000D+02  |                                    |       T=
3.8012D+02
   P=  3.9655D+01  |                                    |       P=
4.0000D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC                 306825.9444
     CALCULATED (REQUIRED) AREA     SQM                          7.0577
     ACTUAL EXCHANGER AREA          SQM                          7.0577
     PER CENT OVER-DESIGN                                        0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K               0.0203
     UA (DIRTY)                     CAL/SEC-K                 1432.8402
```

```
LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                 1.0000
  LMTD (CORRECTED)               C                     214.1383
  NUMBER OF SHELLS IN SERIES                               1

PRESSURE DROP:
  HOTSIDE, TOTAL                 BAR                     0.3447
  COLDSIDE, TOTAL                BAR                     0.3447
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-HX-01 MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |                                                           |---
--->
  800.0  |                                                           |
598.5
         |                                                           |
 COLDOUT |                           VAP                             |
COLDIN
 <------ |                                                           |<--
----
  590.0  |                                                           |
380.1
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     306825.944         7.0577     214.1383     0.0203
1432.8402
```

```
 HEATX COLD-TQCU UP-HX-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:       CONSTANT2
   PRESSURE DROP:          -0.3447     BAR
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    40.0000 !   590.1092 !     1.0000 !
 !  1.4611+04 !    40.0000 !   580.2449 !     1.0000 !
 !  2.9222+04 !    40.0000 !   570.3627 !     1.0000 !
 !  4.3832+04 !    40.0000 !   560.4629 !     1.0000 !
 !  5.8443+04 !    40.0000 !   550.5461 !     1.0000 !
 !------------+------------+------------+------------!
 !  7.3054+04 !    40.0000 !   540.6128 !     1.0000 !
 !  8.7665+04 !    40.0000 !   530.6636 !     1.0000 !
 !  1.0228+05 !    40.0000 !   520.6992 !     1.0000 !
 !  1.1689+05 !    40.0000 !   510.7202 !     1.0000 !
 !  1.3150+05 !    40.0000 !   500.7274 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.4611+05 !    40.0000 !   490.7216 !     1.0000 !
 !  1.6072+05 !    40.0000 !   480.7038 !     1.0000 !
 !  1.7533+05 !    40.0000 !   470.6749 !     1.0000 !
 !  1.8994+05 !    40.0000 !   460.6359 !     1.0000 !
 !  2.0455+05 !    40.0000 !   450.5880 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.1916+05 !    40.0000 !   440.5325 !     1.0000 !
 !  2.3377+05 !    40.0000 !   430.4705 !     1.0000 !
 !  2.4838+05 !    40.0000 !   420.4037 !     1.0000 !
 !  2.6299+05 !    40.0000 !   410.3336 !     1.0000 !
 !  2.7760+05 !    40.0000 !   400.2619 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.9222+05 !    40.0000 !   390.1904 !     1.0000 !
 !  3.0683+05 !    40.0000 !   380.1211 !     1.0000 !
 -----------------------------------------------------
```

```
 HEATX HOT-TQCUR UP-HX-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    39.3105 !   800.0000 !     1.0000 !
 !  1.4611+04 !    39.3105 !   790.6004 !     1.0000 !
 !  2.9222+04 !    39.3105 !   781.1815 !     1.0000 !
 !  4.3832+04 !    39.3105 !   771.7432 !     1.0000 !
 !  5.8443+04 !    39.3105 !   762.2854 !     1.0000 !
 !------------+------------+------------+------------!
 !  7.3054+04 !    39.3105 !   752.8081 !     1.0000 !
 !  8.7665+04 !    39.3105 !   743.3111 !     1.0000 !
 !  1.0228+05 !    39.3105 !   733.7945 !     1.0000 !
 !  1.1689+05 !    39.3105 !   724.2582 !     1.0000 !
 !  1.3150+05 !    39.3105 !   714.7021 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.4611+05 !    39.3105 !   705.1263 !     1.0000 !
 !  1.6072+05 !    39.3105 !   695.5307 !     1.0000 !
 !  1.7533+05 !    39.3105 !   685.9153 !     1.0000 !
 !  1.8994+05 !    39.3105 !   676.2801 !     1.0000 !
 !  2.0455+05 !    39.3105 !   666.6253 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.1916+05 !    39.3105 !   656.9507 !     1.0000 !
 !  2.3377+05 !    39.3105 !   647.2565 !     1.0000 !
 !  2.4838+05 !    39.3105 !   637.5427 !     1.0000 !
 !  2.6299+05 !    39.3105 !   627.8094 !     1.0000 !
 !  2.7760+05 !    39.3105 !   618.0567 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.9222+05 !    39.3105 !   608.2848 !     1.0000 !
 !  3.0683+05 !    39.3105 !   598.4937 !     1.0000 !
 -----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-HX-02 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             12
   OUTLET STREAM:            13
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             5
   OUTLET STREAM:            6
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            648.722         648.722         0.00000
       MASS(KG/HR   )            12284.8         12284.8         0.00000
       ENTHALPY(CAL/SEC )      -0.701648E+07   -0.701648E+07     0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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 OUTLET TEMP
     SPECIFIED VALUE              C                        610.0000
     LMTD CORRECTION FACTOR                                  1.00000
```

```
                             U-O-S BLOCK SECTION

 BLOCK:  UP-HX-02 MODEL: HEATX (CONTINUED)

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                         0.3447
     COLD SIDE PRESSURE DROP        BAR                         0.3447

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K              0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K              0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K              0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K              0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K              0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K              0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K              0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K              0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K              0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   12        ----->|               HOT                  |-----> 13
   T=  8.0000D+02  |                                    |       T=
6.4962D+02
   P=  3.9311D+01  |                                    |       P=
3.8966D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   6         <-----|               COLD                 |<----- 5
   T=  6.1000D+02  |                                    |       T=
5.9000D+02
   P=  3.9311D+01  |                                    |       P=
3.9655D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC                 29852.2398
     CALCULATED (REQUIRED) AREA     SQM                         1.3071
     ACTUAL EXCHANGER AREA          SQM                         1.3071
     PER CENT OVER-DESIGN                                       0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K              0.0203
     UA (DIRTY)                     CAL/SEC-K                 265.3710
```

```
LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                      1.0000
  LMTD (CORRECTED)              C                           112.4925
  NUMBER OF SHELLS IN SERIES                                  1

PRESSURE DROP:
  HOTSIDE, TOTAL                BAR                           0.3447
  COLDSIDE, TOTAL               BAR                           0.3447
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-HX-02 MODEL: HEATX (CONTINUED)

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         --------------------------------------------------------------
         |                                                            |
 HOT IN  |                           VAP                              |
HOT OUT
 ------> |                                                            |---
--->
  800.0  |                                                            |
649.6
         |                                                            |
 COLDOUT |                           VAP                              |
COLDIN
 <------ |                                                            |<--
----
  610.0  |                                                            |
590.0
         |                                                            |
         --------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      29852.240         1.3071     112.4925     0.0203
265.3710
```

```
                              U-O-S BLOCK SECTION

 HEATX COLD-TQCU UP-HX-02 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         -0.3447     BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    39.6553 !   610.1030 !     1.0000 !
 !  1421.5352 !    39.6553 !   609.1475 !     1.0000 !
 !  2843.0705 !    39.6553 !   608.1919 !     1.0000 !
 !  4264.6057 !    39.6553 !   607.2360 !     1.0000 !
 !  5686.1409 !    39.6553 !   606.2800 !     1.0000 !
 !------------+------------+------------+------------!
 !  7107.6761 !    39.6553 !   605.3238 !     1.0000 !
 !  8529.2114 !    39.6553 !   604.3674 !     1.0000 !
 !  9950.7466 !    39.6553 !   603.4108 !     1.0000 !
 !  1.1372+04 !    39.6553 !   602.4540 !     1.0000 !
 !  1.2794+04 !    39.6553 !   601.4971 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.4215+04 !    39.6553 !   600.5400 !     1.0000 !
 !  1.5637+04 !    39.6553 !   599.5827 !     1.0000 !
 !  1.7058+04 !    39.6553 !   598.6252 !     1.0000 !
 !  1.8480+04 !    39.6553 !   597.6676 !     1.0000 !
 !  1.9901+04 !    39.6553 !   596.7097 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.1323+04 !    39.6553 !   595.7517 !     1.0000 !
 !  2.2745+04 !    39.6553 !   594.7936 !     1.0000 !
 !  2.4166+04 !    39.6553 !   593.8352 !     1.0000 !
 !  2.5588+04 !    39.6553 !   592.8767 !     1.0000 !
 !  2.7009+04 !    39.6553 !   591.9180 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.8431+04 !    39.6553 !   590.9591 !     1.0000 !
 !  2.9852+04 !    39.6553 !   590.0000 !     1.0000 !
 -----------------------------------------------------
```

```
                              U-O-S BLOCK SECTION

 HEATX HOT-TQCUR UP-HX-02 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    39.3105 !   800.0000 !     1.0000 !
 !  1421.5352 !    39.3105 !   792.9010 !     1.0000 !
 !  2843.0705 !    39.3105 !   785.7962 !     1.0000 !
 !  4264.6057 !    39.3105 !   778.6856 !     1.0000 !
 !  5686.1409 !    39.3105 !   771.5692 !     1.0000 !
 !------------+------------+------------+------------!
 !  7107.6761 !    39.3105 !   764.4468 !     1.0000 !
 !  8529.2114 !    39.3105 !   757.3183 !     1.0000 !
 !  9950.7466 !    39.3105 !   750.1838 !     1.0000 !
 !  1.1372+04 !    39.3105 !   743.0430 !     1.0000 !
 !  1.2794+04 !    39.3105 !   735.8960 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.4215+04 !    39.3105 !   728.7426 !     1.0000 !
 !  1.5637+04 !    39.3105 !   721.5827 !     1.0000 !
 !  1.7058+04 !    39.3105 !   714.4163 !     1.0000 !
 !  1.8480+04 !    39.3105 !   707.2433 !     1.0000 !
 !  1.9901+04 !    39.3105 !   700.0635 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.1323+04 !    39.3105 !   692.8769 !     1.0000 !
 !  2.2745+04 !    39.3105 !   685.6834 !     1.0000 !
 !  2.4166+04 !    39.3105 !   678.4829 !     1.0000 !
 !  2.5588+04 !    39.3105 !   671.2753 !     1.0000 !
 !  2.7009+04 !    39.3105 !   664.0604 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.8431+04 !    39.3105 !   656.8382 !     1.0000 !
 !  2.9852+04 !    39.3105 !   649.6086 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  UP-MX-01 MODEL: MIXER
 -----------------------------
   INLET STREAMS:         3           20
   OUTLET STREAM:         4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                          ***  MASS AND ENERGY BALANCE  ***
```

```
                                                            IN                         OUT          RELATIVE
DIFF.
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-MX-01 MODEL: MIXER (CONTINUED)
    TOTAL BALANCE
       MOLE(KMOL/HR )             563.122         563.122         0.00000
       MASS(KG/HR   )             9545.73         9545.73       -
0.190555E-15
       ENTHALPY(CAL/SEC )      -0.746717E+07   -0.746717E+07
0.124722E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   ONE    PHASE      FLASH   SPECIFIED PHASE IS  VAPOR
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000
   OUTLET PRESSURE   BAR                                  40.0000

 BLOCK:  UP-MX-02 MODEL: MIXER
 -----------------------------
   INLET STREAMS:         6           9
   OUTLET STREAM:         10A
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )             636.282         636.282         0.00000
       MASS(KG/HR   )             11664.4         11664.4
0.311886E-15
       ENTHALPY(CAL/SEC )      -0.705290E+07   -0.705290E+07   -
0.132048E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-MX-03 MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          10A
   OUTLET STREAM:         10B
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(KMOL/HR )         636.282       620.882      -15.4000
0.00000
   MASS(KG/HR   )         11664.4       11664.4
0.00000
   ENTHALPY(CAL/SEC )   -0.705290E+07 -0.723256E+07
0.248403E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     WATER      1.00    HYDROGEN  -1.00    OXYGEN   -0.500


   REACTION EXTENT SPECS: NUMBER=    1
     REACTION #   1: EXTENT=   30.80     KMOL/HR




   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED TEMPERATURE C                                   800.000
   SPECIFIED PRESSURE    BAR                                  39.3105
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE                                       0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES            NO

                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                      800.00
   OUTLET PRESSURE       BAR                                    39.311
```

```
HEAT DUTY                CAL/SEC                                    -0.17966E+06
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-PM-01 MODEL: PUMP
 ----------------------------
   INLET STREAM:          1
   OUTLET STREAM:         2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            491.700         491.700         0.00000
       MASS(KG/HR   )            8858.11         8858.11         0.00000
       ENTHALPY(CAL/SEC )      -0.942335E+07   -0.941751E+07   -
0.619183E-03

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR                                   40.0000
    DRIVER EFFICIENCY                                       1.00000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                            30
    TOLERANCE                                               0.000100000

                           ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  L/MIN                           153.615
    PRESSURE CHANGE  BAR                                   39.0000
    NPSH AVAILABLE   M-KGF/KG                              10.3610
    FLUID POWER  KW                                         9.98495
    BRAKE POWER  KW                                        24.4291
    ELECTRICITY  KW                                        24.4291
    PUMP EFFICIENCY USED                                    0.40873
    NET WORK REQUIRED  KW                                  24.4291
    HEAD DEVELOPED M-KGF/KG                               413.796

 BLOCK:  UP-SE-01 MODEL: SEP
 ---------------------------
   INLET STREAM:          16
   OUTLET STREAMS:        18          17
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-SE-01 MODEL: SEP (CONTINUED)


***********************************************************************
     *
*
     *     SUM OF SPLITS SPECIFIED IS ILLEGAL
*
     *
*

***********************************************************************


                      ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            620.882         620.882
0.577485E-06
       MASS(KG/HR   )            8925.35         8925.35
0.990596E-07
       ENTHALPY(CAL/SEC )      -0.670452E+07   -0.670542E+07
0.134095E-03

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR


                          ***  INPUT DATA  ***

   FLASH SPECS FOR STREAM 18
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED PRESSURE    BAR                                 38.9313
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   FLASH SPECS FOR STREAM 17
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  LIQUID
   PRESSURE DROP         BAR                                  0.0
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
```

```
                              U-O-S BLOCK SECTION

 BLOCK:  UP-SE-01 MODEL: SEP (CONTINUED)

   MOLE-FLOW (KMOL/HR )
     SUBSTREAM= MIXED
       STREAM= 18        CPT= WATER     FLOW=              0.0
                              HYDROGEN                   232.800
                              NITROGEN                    77.6000
                              OXYGEN                       0.0
                              ARGON                        0.90000


                           ***  RESULTS  ***

   HEAT DUTY             CAL/SEC                             -899.15

  COMPONENT = WATER
    STREAM     SUBSTREAM    SPLIT FRACTION
    17         MIXED                1.00000

  COMPONENT = HYDROGEN
    STREAM     SUBSTREAM    SPLIT FRACTION
    18         MIXED                1.00000

  COMPONENT = NITROGEN
    STREAM     SUBSTREAM    SPLIT FRACTION
    18         MIXED                0.99918
    17         MIXED                0.00082406

  COMPONENT = ARGON
    STREAM     SUBSTREAM    SPLIT FRACTION
    18         MIXED                1.00000

 BLOCK:  UP-SP-01 MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          18
   OUTLET STREAMS:        19          21
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            269.518         269.518         0.00000
       MASS(KG/HR   )            2594.79         2594.79         0.00000
       ENTHALPY(CAL/SEC )        5179.84         5179.84         0.00000
```

```
                             U-O-S BLOCK SECTION

 BLOCK:  UP-SP-01 MODEL: FSPLIT (CONTINUED)

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR

                         ***  INPUT DATA  ***

  FRACTION OF FLOW                 STRM=19       FRAC=         0.26500

                          ***  RESULTS  ***

  STREAM= 19             SPLIT=          0.26500     KEY=  0    STREAM-
ORDER=   1
          21                             0.73500           0
2
```

```
                                STREAM SECTION

 1 10A 10B 11 12
 ---------------

 STREAM ID                1          10A        10B        11         12
 FROM :                   ----       UP-MX-02   UP-MX-03   SOEC2
SOEC2
 TO   :                   UP-PM-01   UP-MX-03   SOEC       UP-HX-01   UP-
HX-02

 SUBSTREAM: MIXED
 PHASE:                   LIQUID     VAPOR      VAPOR      VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   WATER                 491.7000   491.7000   522.5000   351.3000     0.0
   HYDROGEN                0.0       50.6203    19.8203   191.0203     0.0
   NITROGEN                0.0       77.6640    77.6640    77.6640     0.0
   OXYGEN                  0.0       15.4000     0.0        0.0
85.6000
   ARGON                   0.0        0.8980     0.8980     0.8980     0.0
 TOTAL FLOW:
   KMOL/HR               491.7000   636.2822   620.8822   620.8822
85.6000
   KG/HR                8858.1132  1.1664+04  1.1664+04  8925.3523
2739.0973
   L/MIN                 153.6146  1.9539+04  2.3484+04  2.3589+04
3269.1917
 STATE VARIABLES:
   TEMP   C               25.0000   603.3524   800.0000   800.0000
800.0000
   PRES   BAR              1.0000    39.3105    39.3105    39.3105
39.3105
   VFRAC                   0.0        1.0000     1.0000     1.0000
1.0000
   LFRAC                   1.0000     0.0        0.0        0.0        0.0
   SFRAC                   0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL              -6.8993+04 -3.9904+04 -4.1936+04 -2.6373+04
6050.0777
   CAL/GM               -3829.7161 -2176.7382 -2232.1863 -1834.5980
189.0720
   CAL/SEC              -9.4233+06 -7.0529+06 -7.2326+06 -4.5485+06
1.4386+05
 ENTROPY:
   CAL/MOL-K             -38.9834    -5.1890    -4.3373    -1.1313
2.4981
   CAL/GM-K               -2.1639    -0.2831    -0.2309 -7.8699-02
7.8067-02
 DENSITY:
```

```
   MOL/CC                5.3348-02  5.4275-04  4.4064-04  4.3868-04
4.3640-04
   GM/CC                    0.9611  9.9499-03  8.2783-03  6.3062-03
1.3964-02
 AVG MW                    18.0153    18.3322    18.7869    14.3753
31.9988
```

```
                                 STREAM SECTION

 13 14 15 16 17
 --------------

 STREAM ID                13         14         15         16         17
 FROM :                   UP-HX-02   UP-CO-03   UP-HX-01   UP-CD-01   UP-
SE-01
 TO   :                   UP-CO-03   ----       UP-CD-01   UP-SE-01   ----


 CONV. MAX. REL. ERR:      0.0        0.0     4.7370-06     0.0        0.0
 SUBSTREAM: MIXED
 PHASE:                   VAPOR      VAPOR      VAPOR      MIXED
LIQUID
 COMPONENTS: KMOL/HR
   WATER                   0.0        0.0      351.3000   351.3000
351.3000
   HYDROGEN                0.0        0.0      191.0203   191.0203     0.0
   NITROGEN                0.0        0.0       77.6640    77.6640
6.4000-02
   OXYGEN                 85.6000    85.6000     0.0        0.0        0.0
   ARGON                   0.0        0.0        0.8980     0.8980     0.0
 TOTAL FLOW:
   KMOL/HR                85.6000    85.6000   620.8822   620.8822
351.3640
   KG/HR                2739.0973  2739.0973  8925.3523  8925.3523
6330.5607
   L/MIN                2838.9851   924.6971  1.9265+04  3129.5856
110.7025
 STATE VARIABLES:
   TEMP   C              649.6228    35.0000   598.4517    35.0000
35.0000
   PRES   BAR             38.9658    38.9313    38.9658    38.9313
38.9313
   VFRAC                   1.0000     1.0000     1.0000     0.4347     0.0
   LFRAC                   0.0        0.0        0.0        0.5653
1.0000
   SFRAC                   0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL              4794.6097     0.3049 -2.8152+04 -3.8874+04 -
6.8755+04
   CAL/GM                149.8372  9.5286-03 -1958.3548 -2704.2386 -
3816.1179
   CAL/SEC              1.1401+05     7.2499 -4.8553+06 -6.7045+06 -
6.7106+06
 ENTROPY:
   CAL/MOL-K               1.2556    -7.2082    -2.9486   -24.2343   -
38.3942
   CAL/GM-K             3.9239-02    -0.2253    -0.2051    -1.6858    -
2.1310
```

```
 DENSITY:
   MOL/CC              5.0253-04  1.5428-03  5.3715-04  3.3065-03
5.2899-02
   GM/CC               1.6080-02  4.9369-02  7.7216-03  4.7532-02
0.9531
 AVG MW                  31.9988    31.9988    14.3753    14.3753
18.0171
```

```
                                 STREAM SECTION

 18 19 2 20 21
 -------------

 STREAM ID               18         19         2          20         21
 FROM :                  UP-SE-01   UP-SP-01   UP-PM-01   UP-CP-04   UP-
SP-01
 TO   :                  UP-SP-01   UP-CP-04   UP-BO-01   UP-MX-01   ----

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      VAPOR      LIQUID     VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   WATER                  0.0        0.0      491.7000     0.0        0.0
   HYDROGEN             191.0199    50.6203     0.0       50.6203
140.3996
   NITROGEN              77.6000    20.5640     0.0       20.5640
57.0360
   OXYGEN                 0.0        0.0        0.0        0.0        0.0
   ARGON                  0.8980     0.2380     0.0        0.2380
0.6600
 TOTAL FLOW:
   KMOL/HR              269.5179    71.4222   491.7000    71.4222
198.0956
   KG/HR               2594.7907   687.6195  8858.1132   687.6195
1907.1712
   L/MIN               3014.9374   798.9584   153.6654   786.4963
2215.9790
 STATE VARIABLES:
   TEMP   C              35.0000    35.0000    26.2138    38.3557
35.0000
   PRES   BAR            38.9313    38.9313    40.0000    40.0000
38.9313
   VFRAC                  1.0000     1.0000     0.0        1.0000
1.0000
   LFRAC                  0.0        0.0        1.0000     0.0        0.0
   SFRAC                  0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL               69.1881    69.1881 -6.8951+04    92.7604
69.1881
   CAL/GM                 7.1865     7.1865 -3827.3448     9.6349
7.1865
   CAL/SEC             5179.8437  1372.6586 -9.4175+06  1840.3216
3807.1851
 ENTROPY:
   CAL/MOL-K             -5.8222    -5.8222   -38.9164    -5.8010    -
5.8222
   CAL/GM-K              -0.6047    -0.6047    -2.1602    -0.6025    -
0.6047
 DENSITY:
```

```
   MOL/CC               1.4899-03  1.4899-03  5.3330-02  1.5135-03
1.4899-03
   GM/CC                1.4344-02  1.4344-02     0.9608  1.4571-02
1.4344-02
  AVG MW                   9.6275     9.6275    18.0153     9.6275
9.6275
```

```
                                 STREAM SECTION

 3 4 5 6 7
 ---------

 STREAM ID               3          4          5          6          7
 FROM :                  UP-BO-01   UP-MX-01   UP-HX-01   UP-HX-02   ----
 TO   :                  UP-MX-01   UP-HX-01   UP-HX-02   UP-MX-02   UP-
CP-01

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      VAPOR      VAPOR      VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   WATER                491.7000   491.7000   491.7000   491.7000     0.0
   HYDROGEN               0.0       50.6203    50.6203    50.6203     0.0
   NITROGEN               0.0       20.5640    20.5640    20.5640
57.1000
   OXYGEN                 0.0        0.0        0.0        0.0
15.4000
   ARGON                  0.0        0.2380     0.2380     0.2380
0.6600
 TOTAL FLOW:
   KMOL/HR              491.7000   563.1222   563.1222   563.1222
73.1600
   KG/HR               8858.1132  9545.7327  9545.7327  9545.7327
2118.7169
   L/MIN               1.1223+04  1.2184+04  1.6781+04  1.7349+04
3.0222+04
 STATE VARIABLES:
   TEMP   C             420.0000   380.1211   590.0000   610.0000
25.0000
   PRES   BAR            40.0000    40.0000    39.6553    39.3105
1.0000
   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:
   CAL/MOL            -5.4685+04 -4.7737+04 -4.5776+04 -4.5585+04    -
1.5891
   CAL/GM             -3035.4576 -2816.1067 -2700.3928 -2689.1346 -
5.4873-02
   CAL/SEC            -7.4690+06 -7.4672+06 -7.1603+06 -7.1305+06   -
32.2948
 ENTROPY:
   CAL/MOL-K            -11.1286    -9.5045    -6.8853    -6.6495
1.1410
   CAL/GM-K              -0.6177    -0.5607    -0.4062    -0.3923
3.9399-02
 DENSITY:
```

```
   MOL/CC               7.3021-04  7.7029-04  5.5928-04  5.4097-04
4.0347-05
   GM/CC                1.3155-02  1.3058-02  9.4805-03  9.1703-03
1.1684-03
 AVG MW                   18.0153    16.9514    16.9514    16.9514
28.9600
```

```
                                 STREAM SECTION

 7A 7B 7C 7D 8
 -------------

 STREAM ID               7A         7B         7C         7D         8
 FROM :                  UP-CP-01   UP-CO-01   UP-CP-02   UP-CO-02   UP-
CP-03
 TO   :                  UP-CO-01   UP-CP-02   UP-CO-02   UP-CP-03   UP-
FH-01

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      VAPOR      VAPOR      VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   WATER                  0.0        0.0        0.0        0.0        0.0
   HYDROGEN               0.0        0.0        0.0        0.0        0.0
   NITROGEN              57.1000    57.1000    57.1000    57.1000
57.1000
   OXYGEN                15.4000    15.4000    15.4000    15.4000
15.4000
   ARGON                  0.6600     0.6600     0.6600     0.6600
0.6600
 TOTAL FLOW:
   KMOL/HR               73.1600    73.1600    73.1600    73.1600
73.1600
   KG/HR                2118.7169  2118.7169  2118.7169  2118.7169
2118.7169
   L/MIN                1.3983+04  1.0248+04  4435.9706  2774.9582
1279.2606
 STATE VARIABLES:
   TEMP   C              197.9118    37.7778   236.2172    37.7778
222.9051
   PRES   BAR              3.4200     3.0753    11.7000    11.3553
40.0000
   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:
   CAL/MOL              1210.0985    84.4361  1481.8340    72.7828
1382.1251
   CAL/GM                41.7851     2.9156    51.1682     2.5132
47.7252
   CAL/SEC              2.4592+04  1715.9285  3.0114+04  1479.1084
2.8088+04
 ENTROPY:
   CAL/MOL-K              1.9005    -0.8070  5.6172-03    -3.4379    -
2.6584
   CAL/GM-K             6.5626-02 -2.7865-02  1.9396-04    -0.1187 -
9.1795-02
```

```
 DENSITY:
   MOL/CC              8.7198-05  1.1898-04  2.7487-04  4.3941-04
9.5315-04
   GM/CC               2.5253-03  3.4456-03  7.9604-03  1.2725-02
2.7603-02
 AVG MW                  28.9600    28.9600    28.9600    28.9600
28.9600
```

```
                                 STREAM SECTION

 9 CW1 CW2 CW3 CW4
 -----------------

 STREAM ID                 9           CW1         CW2         CW3         CW4
 FROM :                    UP-FH-01    ----        UP-CO-01    UP-CO-02    ----
 TO   :                    UP-MX-02    UP-CO-01    UP-CO-02    ----        UP-
CO-03

 SUBSTREAM: MIXED
 PHASE:                    VAPOR       LIQUID      LIQUID      LIQUID
LIQUID
 COMPONENTS: KMOL/HR
   WATER                     0.0       403.0176    403.0176    403.0176
889.6555
   HYDROGEN                  0.0         0.0         0.0         0.0         0.0
   NITROGEN                 57.1000      0.0         0.0         0.0         0.0
   OXYGEN                   15.4000      0.0         0.0         0.0         0.0
   ARGON                     0.6600      0.0         0.0         0.0         0.0
 TOTAL FLOW:
   KMOL/HR                  73.1600    403.0176    403.0176    403.0176
889.6555
   KG/HR                  2118.7169   7260.4752   7260.4752   7260.4752
1.6027+04
   L/MIN                  2116.7436    126.0963    127.2374    128.7475
273.7279
 STATE VARIABLES:
   TEMP   C                550.0000     26.6667     36.5319     48.8889
7.2222
   PRES   BAR               40.0000      1.0000      1.0000      1.0000
1.0000
   VFRAC                     1.0000      0.0         0.0         0.0         0.0
   LFRAC                     0.0         1.0000      1.0000      1.0000
1.0000
   SFRAC                     0.0         0.0         0.0         0.0         0.0
 ENTHALPY:
   CAL/MOL                3817.7504 -6.8959+04 -6.8755+04 -6.8499+04 -
6.9363+04
   CAL/GM                  131.8282 -3827.7985 -3816.4558 -3802.2575 -
3850.2092
   CAL/SEC                7.7585+04 -7.7199+06 -7.6970+06 -7.6684+06 -
1.7141+07
 ENTROPY:
   CAL/MOL-K                 1.1037    -38.8832    -38.3020    -37.5995   -
40.0894
   CAL/GM-K               3.8112-02     -2.1583     -2.1261     -2.0871    -
2.2253
 DENSITY:
   MOL/CC                 5.7604-04  5.3269-02  5.2791-02  5.2172-02
5.4169-02
```

```
   GM/CC                1.6682-02     0.9596     0.9510     0.9399
0.9759
 AVG MW                   28.9600    18.0153    18.0153    18.0153
18.0153
```

```
                                 STREAM SECTION

 CW5 CW6 CW7 SOEC1
 -----------------

 STREAM ID                CW5         CW6         CW7         SOEC1
 FROM :                   UP-CO-03    ----        UP-CD-01    SOEC
 TO   :                   ----        UP-CD-01    ----        SOEC2

 SUBSTREAM: MIXED
 PHASE:                   LIQUID      LIQUID      LIQUID      VAPOR
 COMPONENTS: KMOL/HR
   WATER                 889.6555   6392.4052   6392.4052    351.3000
   HYDROGEN                0.0         0.0         0.0       191.0203
   NITROGEN                0.0         0.0         0.0        77.6640
   OXYGEN                  0.0         0.0         0.0        85.6000
   ARGON                   0.0         0.0         0.0         0.8980
 TOTAL FLOW:
   KMOL/HR               889.6555   6392.4052   6392.4052    706.4822
   KG/HR                1.6027+04   1.1516+05   1.1516+05   1.1664+04
   L/MIN                 279.0528   1928.2758   2010.1432   2.6866+04
 STATE VARIABLES:
   TEMP   C               29.4444    -17.7778     32.2222    800.0000
   PRES   BAR              1.0000      1.0000      1.0000     39.3105
   VFRAC                   0.0         0.0         0.0         1.0000
   LFRAC                   1.0000      1.0000      1.0000      0.0
   SFRAC                   0.0         0.0         0.0         0.0
 ENTHALPY:
   CAL/MOL             -6.8901+04 -6.9885+04 -6.8844+04 -2.2443+04
   CAL/GM              -3824.6035 -3879.2179 -3821.4095 -1359.2898
   CAL/SEC             -1.7027+07 -1.2409+08 -1.2224+08 -4.4043+06
 ENTROPY:
   CAL/MOL-K             -38.7176    -41.7323    -38.5536   4.2610-02
   CAL/GM-K               -2.1492     -2.3165     -2.1400   2.5808-03
 DENSITY:
   MOL/CC               5.3135-02   5.5251-02   5.3001-02   4.3827-04
   GM/CC                  0.9572      0.9954      0.9548    7.2361-03
 AVG MW                  18.0153     18.0153     18.0153     16.5106
```

```
                             PROBLEM STATUS SECTION

 BLOCK STATUS
 ------------


*************************************************************************
***
 *
*
 * Calculations were completed with warnings
*
 *
*
 * The following Unit Operation blocks were
*
 * completed with warnings:
*
 *   UP-SE-01
*
 *
*
 * All streams were flashed normally
*
 *
*
 * All Convergence blocks were completed normally
*
 *
*

*************************************************************************
***
```

B.1.4 SOEC Block Summary

```
 BLOCK:  SOEC     MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          10B
   OUTLET STREAM:         SOEC1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                             IN          OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(KMOL/HR )         620.882       706.482       85.6000
0.00000
   MASS(KG/HR   )         11664.4       11664.4
0.00000
   ENTHALPY(CAL/SEC )   -0.723256E+07 -0.440427E+07                 -
0.391050

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR

                          ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     WATER     -1.00    HYDROGEN   1.00    OXYGEN    0.500


   REACTION EXTENT SPECS: NUMBER=    1
     REACTION #   1: EXTENT=   171.2     KMOL/HR




   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE C                                  800.000
   SPECIFIED PRESSURE    BAR                                 39.3105
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES           NO

                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                     800.00
   OUTLET PRESSURE       BAR                                   39.311
   HEAT DUTY             CAL/SEC                              0.28283E+07
   VAPOR FRACTION                                              1.0000
```

```
   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)           K(I)
      WATER            0.49725        0.49725        0.49725
MISSING
      HYDROGEN         0.27038        0.27038        0.27038
MISSING
      NITROGEN         0.10993        0.10993        0.10993
MISSING
      OXYGEN           0.12116        0.12116        0.12116
MISSING
      ARGON            0.12710E-02    0.12710E-02    0.12710E-02
MISSING

 BLOCK:  SOEC2    MODEL: SEP
 ---------------------------
   INLET STREAM:          SOEC1
   OUTLET STREAMS:        11          12
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           706.482         706.482         0.00000
       MASS(KG/HR   )           11664.4         11664.4         0.00000
       ENTHALPY(CAL/SEC )      -0.440427E+07   -0.440460E+07
0.743308E-04

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR


                        ***  INPUT DATA  ***

   FLASH SPECS FOR STREAM 11
   TWO    PHASE  TP  FLASH
   PRESSURE DROP         BAR                                 0.0
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FLASH SPECS FOR STREAM 12
   TWO    PHASE  TP  FLASH
   PRESSURE DROP         BAR                                 0.0
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FRACTION OF FEED
```

```
    SUBSTREAM= MIXED
      STREAM= 12        CPT= WATER     FRACTION=          0.0
                             HYDROGEN                     0.0
                             NITROGEN                     0.0
                             ARGON                        0.0

  MOLE-FLOW (KMOL/HR )
    SUBSTREAM= MIXED
      STREAM= 12        CPT= OXYGEN    FLOW=             85.6000


                       ***  RESULTS  ***

  HEAT DUTY             CAL/SEC                             -327.40

 COMPONENT = WATER
   STREAM     SUBSTREAM    SPLIT FRACTION
   11         MIXED                 1.00000

 COMPONENT = HYDROGEN
   STREAM     SUBSTREAM    SPLIT FRACTION
   11         MIXED                 1.00000

 COMPONENT = NITROGEN
   STREAM     SUBSTREAM    SPLIT FRACTION
   11         MIXED                 1.00000

 COMPONENT = OXYGEN
   STREAM     SUBSTREAM    SPLIT FRACTION
   12         MIXED                 1.00000

 COMPONENT = ARGON
   STREAM     SUBSTREAM    SPLIT FRACTION
   11         MIXED                 1.00000

 BLOCK:  UP-BO-01 MODEL: HEATER
 ------------------------------
   INLET STREAM:          2
   OUTLET STREAM:         3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           491.700         491.700         0.00000
       MASS(KG/HR   )           8858.11         8858.11         0.00000
       ENTHALPY(CAL/SEC )     -0.941751E+07   -0.746901E+07   -0.206903

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
```

```
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                C                       420.000
   SPECIFIED PRESSURE                   BAR                      40.0000
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE
0.000100000



                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                    420.00
   OUTLET PRESSURE       BAR                                  40.000
   HEAT DUTY             CAL/SEC                             0.19485E+07
   OUTLET VAPOR FRACTION                                      1.0000



   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)           K(I)
      WATER             1.0000         1.0000         1.0000
MISSING

 BLOCK:  UP-CD-01 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             15
   OUTLET STREAM:            16
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             CW6
   OUTLET STREAM:            CW7
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            7013.29         7013.29         0.00000
       MASS(KG/HR   )            124086.         124086.         0.00000
       ENTHALPY(CAL/SEC )      -0.128948E+09   -0.128948E+09   -
0.231119E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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                      35.0000
     LMTD CORRECTION FACTOR                                 1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                     0.0345
     COLD SIDE PRESSURE DROP        BAR                     0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K          0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K          0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K          0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K          0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K          0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K          0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K          0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K          0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K          0.0203

                       ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   15        ----->|               HOT                  |-----> 16
   T=  5.9845D+02  |                                    |       T=
3.5000D+01
   P=  3.8966D+01  |                                    |       P=
3.8931D+01
   V=  1.0000D+00  |                                    |       V=
4.3473D-01
                   |                                    |
   CW7       <-----|               COLD                 |<----- CW6
   T=  3.2222D+01  |                                    |       T= -
1.7778D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
```

```
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC             1849243.1706
     CALCULATED (REQUIRED) AREA     SQM                      65.9652
     ACTUAL EXCHANGER AREA          SQM                      65.9652
     PER CENT OVER-DESIGN                                     0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K            0.0203
     UA (DIRTY)                     CAL/SEC-K            13392.1917

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                   1.0000
     LMTD (CORRECTED)               C                       138.0837
     NUMBER OF SHELLS IN SERIES                                1

   PRESSURE DROP:
     HOTSIDE, TOTAL                 BAR                       0.0345
     COLDSIDE, TOTAL                BAR                       0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                             |                             |
 HOT IN  |             VAP             |             COND            |
HOT OUT
 ------> |                             |                             |---
--->
  598.5  |                        213.7|                             |
35.0
         |                             |                             |
 COLDOUT |             LIQ             |             LIQ             |
COLDIN
 <------ |                             |                             |<--
----
   32.2  |                         17.0|                             |  -
17.8
         |                             |                             |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     559364.539         7.8838     349.4788     0.0203
1600.5680
     2    1289878.632        58.0814     109.3894     0.0203
11791.6237
```

```
HEATX COLD-TQCU UP-CD-01 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !     1.0000 !    32.2222 !     0.0    !
!  8.8059+04 !     1.0000 !    29.8281 !     0.0    !
!  1.7612+05 !     1.0000 !    27.4346 !     0.0    !
!  2.6418+05 !     1.0000 !    25.0420 !     0.0    !
!  3.5224+05 !     1.0000 !    22.6501 !     0.0    !
!------------+------------+------------+------------!
!  4.4030+05 !     1.0000 !    20.2593 !     0.0    !
!  5.2836+05 !     1.0000 !    17.8695 !     0.0    !
!  5.5935+05 !     1.0000 !    17.0286 !     0.0    !
!  6.1641+05 !     1.0000 !    15.4810 !     0.0    !
!  7.0447+05 !     1.0000 !    13.0937 !     0.0    !
!------------+------------+------------+------------!
!  7.9253+05 !     1.0000 !    10.7078 !     0.0    !
!  8.8059+05 !     1.0000 !     8.3234 !     0.0    !
!  9.6865+05 !     1.0000 !     5.9405 !     0.0    !
!  1.0567+06 !     1.0000 !     3.5594 !     0.0    !
!  1.1448+06 !     1.0000 !     1.1801 !     0.0    !
!------------+------------+------------+------------!
!  1.2328+06 !     1.0000 !    -1.1974 !     0.0    !
!  1.3209+06 !     1.0000 !    -3.5728 !     0.0    !
!  1.4089+06 !     1.0000 !    -5.9461 !     0.0    !
!  1.4970+06 !     1.0000 !    -8.3173 !     0.0    !
!  1.5851+06 !     1.0000 !   -10.6861 !     0.0    !
!------------+------------+------------+------------!
!  1.6731+06 !     1.0000 !   -13.0525 !     0.0    !
!  1.7612+06 !     1.0000 !   -15.4165 !     0.0    !
!  1.8492+06 !     1.0000 !   -17.7778 !     0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR UP-CD-01 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
```

```
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    38.9658 !   598.4517 !     1.0000 !
 !  8.8059+04 !    38.9658 !   539.0362 !     1.0000 !
 !  1.7612+05 !    38.9658 !   478.9835 !     1.0000 !
 !  2.6418+05 !    38.9658 !   418.3820 !     1.0000 !
 !  3.5224+05 !    38.9658 !   357.3703 !     1.0000 !
 !------------+------------+------------+------------!
 !  4.4030+05 !    38.9658 !   296.1613 !     1.0000 !
 !  5.2836+05 !    38.9658 !   235.0891 !     1.0000 !
 !  5.5935+05 !    38.9658 !   213.7170 ! DEW>1.0000 !
 !  6.1641+05 !    38.9658 !   212.1274 !     0.9619 !
 !  7.0447+05 !    38.9658 !   209.3752 !     0.9040 !
 !------------+------------+------------+------------!
 !  7.9253+05 !    38.9658 !   206.1884 !     0.8472 !
 !  8.8059+05 !    38.9658 !   202.4636 !     0.7919 !
 !  9.6865+05 !    38.9658 !   198.0651 !     0.7382 !
 !  1.0567+06 !    38.9658 !   192.8126 !     0.6865 !
 !  1.1448+06 !    38.9658 !   186.4635 !     0.6375 !
 !------------+------------+------------+------------!
 !  1.2328+06 !    38.9658 !   178.6899 !     0.5917 !
 !  1.3209+06 !    38.9658 !   169.0453 !     0.5499 !
 !  1.4089+06 !    38.9658 !   156.9273 !     0.5131 !
 !  1.4970+06 !    38.9658 !   141.5472 !     0.4825 !
 !  1.5851+06 !    38.9658 !   121.9693 !     0.4594 !
 !------------+------------+------------+------------!
 !  1.6731+06 !    38.9658 !    97.3929 !     0.4445 !
 !  1.7612+06 !    38.9658 !    67.8882 !     0.4372 !
 !  1.8492+06 !    38.9658 !    34.9997 !     0.4347 !
 -----------------------------------------------------

 BLOCK:  UP-CO-01 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             7A
   OUTLET STREAM:            7B
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             CW1
   OUTLET STREAM:            CW2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            476.178         476.178         0.00000
       MASS(KG/HR   )            9379.19         9379.19         0.00000
       ENTHALPY(CAL/SEC )      -0.769531E+07   -0.769531E+07     0.00000
```

```
                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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                       37.7778
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.3447
     COLD SIDE PRESSURE DROP        BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   7A        ----->|               HOT                  |-----> 7B
   T=  1.9791D+02  |                                    |       T=
3.7778D+01
   P=  3.4200D+00  |                                    |       P=
3.0753D+00
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   CW2       <-----|               COLD                 |<----- CW1
```

```
   T=  3.6532D+01  |                                    |       T=
2.6667D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY          CAL/SEC              22875.9612
     CALCULATED (REQUIRED) AREA    SQM                      2.0065
     ACTUAL EXCHANGER AREA         SQM                      2.0065
     PER CENT OVER-DESIGN                                   0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)   CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                    CAL/SEC-K              407.3491

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                 1.0000
     LMTD (CORRECTED)              C                       56.1581
     NUMBER OF SHELLS IN SERIES                            1

   PRESSURE DROP:
     HOTSIDE, TOTAL                BAR                      0.3447
     COLDSIDE, TOTAL               BAR                      0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |                                                           |---
--->
  197.9  |                                                           |
37.8
         |                                                           |
 COLDOUT |                           LIQ                             |
COLDIN
 <------ |                                                           |<--
----
   36.5  |                                                           |
26.7
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA        LMTD        AVERAGE U       UA
```

```
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      22875.961         2.0065      56.1581     0.0203
407.3491

 HEATX COLD-TQCU UP-CO-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     1.0000 !    36.5319 !     0.0    !
 !  1089.3315 !     1.0000 !    36.0619 !     0.0    !
 !  2178.6630 !     1.0000 !    35.5919 !     0.0    !
 !  3267.9945 !     1.0000 !    35.1220 !     0.0    !
 !  4357.3259 !     1.0000 !    34.6521 !     0.0    !
 !------------+------------+------------+------------!
 !  5446.6574 !     1.0000 !    34.1822 !     0.0    !
 !  6535.9889 !     1.0000 !    33.7123 !     0.0    !
 !  7625.3204 !     1.0000 !    33.2424 !     0.0    !
 !  8714.6519 !     1.0000 !    32.7725 !     0.0    !
 !  9803.9834 !     1.0000 !    32.3027 !     0.0    !
 !------------+------------+------------+------------!
 !  1.0893+04 !     1.0000 !    31.8329 !     0.0    !
 !  1.1983+04 !     1.0000 !    31.3631 !     0.0    !
 !  1.3072+04 !     1.0000 !    30.8934 !     0.0    !
 !  1.4161+04 !     1.0000 !    30.4236 !     0.0    !
 !  1.5251+04 !     1.0000 !    29.9539 !     0.0    !
 !------------+------------+------------+------------!
 !  1.6340+04 !     1.0000 !    29.4842 !     0.0    !
 !  1.7429+04 !     1.0000 !    29.0146 !     0.0    !
 !  1.8519+04 !     1.0000 !    28.5449 !     0.0    !
 !  1.9608+04 !     1.0000 !    28.0753 !     0.0    !
 !  2.0697+04 !     1.0000 !    27.6057 !     0.0    !
 !------------+------------+------------+------------!
 !  2.1787+04 !     1.0000 !    27.1362 !     0.0    !
 !  2.2876+04 !     1.0000 !    26.6667 !     0.0    !
 -----------------------------------------------------

 HEATX HOT-TQCUR UP-CO-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
```

```
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     3.4200 !   197.9118 !     1.0000 !
 !  1089.3315 !     3.4200 !   190.3568 !     1.0000 !
 !  2178.6630 !     3.4200 !   182.7929 !     1.0000 !
 !  3267.9945 !     3.4200 !   175.2203 !     1.0000 !
 !  4357.3259 !     3.4200 !   167.6394 !     1.0000 !
 !------------+------------+------------+------------!
 !  5446.6574 !     3.4200 !   160.0505 !     1.0000 !
 !  6535.9889 !     3.4200 !   152.4540 !     1.0000 !
 !  7625.3204 !     3.4200 !   144.8500 !     1.0000 !
 !  8714.6519 !     3.4200 !   137.2391 !     1.0000 !
 !  9803.9834 !     3.4200 !   129.6216 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.0893+04 !     3.4200 !   121.9979 !     1.0000 !
 !  1.1983+04 !     3.4200 !   114.3684 !     1.0000 !
 !  1.3072+04 !     3.4200 !   106.7334 !     1.0000 !
 !  1.4161+04 !     3.4200 !    99.0935 !     1.0000 !
 !  1.5251+04 !     3.4200 !    91.4489 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.6340+04 !     3.4200 !    83.8003 !     1.0000 !
 !  1.7429+04 !     3.4200 !    76.1480 !     1.0000 !
 !  1.8519+04 !     3.4200 !    68.4925 !     1.0000 !
 !  1.9608+04 !     3.4200 !    60.8342 !     1.0000 !
 !  2.0697+04 !     3.4200 !    53.1737 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.1787+04 !     3.4200 !    45.5114 !     1.0000 !
 !  2.2876+04 !     3.4200 !    37.8479 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  UP-CO-02 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             7C
   OUTLET STREAM:            7D
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             CW2
   OUTLET STREAM:            CW3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            476.178          476.178          0.00000
       MASS(KG/HR   )            9379.19          9379.19          0.00000
```

```
       ENTHALPY(CAL/SEC )      -0.766691E+07   -0.766691E+07
0.121473E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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                       37.7778
     LMTD CORRECTION FACTOR                                 1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP       BAR                      0.3447
     COLD SIDE PRESSURE DROP       BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K          0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K          0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K          0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K          0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K          0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K          0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K          0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K          0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K          0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   7C        ----->|                HOT                 |-----> 7D
   T=  2.3622D+02  |                                    |       T=
3.7778D+01
   P=  1.1700D+01  |                                    |       P=
1.1355D+01
```

```
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   CW3       <-----|               COLD                 |<----- CW2
   T=  4.8889D+01  |                                    |       T=
3.6532D+01
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY            CAL/SEC                 28635.0522
     CALCULATED (REQUIRED) AREA      SQM                         3.7997
     ACTUAL EXCHANGER AREA           SQM                         3.7997
     PER CENT OVER-DESIGN                                        0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     CAL/SEC-SQCM-K              0.0203
     UA (DIRTY)                      CAL/SEC-K                 771.4194

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                      1.0000
     LMTD (CORRECTED)                C                          37.1200
     NUMBER OF SHELLS IN SERIES                                 1

   PRESSURE DROP:
     HOTSIDE, TOTAL                  BAR                         0.3447
     COLDSIDE, TOTAL                 BAR                         0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                    HOT
         -------------------------------------------------------------
         |                                                           |
  HOT IN |                          VAP                              |
HOT OUT
  ------> |                                                          |---
--->
   236.2 |                                                           |
37.8
         |                                                           |
 COLDOUT |                          LIQ                              |
COLDIN
  <------ |                                                          |<--
----
    48.9 |                                                           |
36.5
         |                                                           |
         -------------------------------------------------------------
                                    COLD
```

```
   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      28635.052         3.7997      37.1200     0.0203
771.4194

 HEATX COLD-TQCU UP-CO-02 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     1.0000 !    48.8889 !     0.0    !
 !  1363.5739 !     1.0000 !    48.3004 !     0.0    !
 !  2727.1478 !     1.0000 !    47.7120 !     0.0    !
 !  4090.7217 !     1.0000 !    47.1235 !     0.0    !
 !  5454.2957 !     1.0000 !    46.5351 !     0.0    !
 !------------+------------+------------+------------!
 !  6817.8696 !     1.0000 !    45.9466 !     0.0    !
 !  8181.4435 !     1.0000 !    45.3581 !     0.0    !
 !  9545.0174 !     1.0000 !    44.7696 !     0.0    !
 !  1.0909+04 !     1.0000 !    44.1812 !     0.0    !
 !  1.2272+04 !     1.0000 !    43.5927 !     0.0    !
 !------------+------------+------------+------------!
 !  1.3636+04 !     1.0000 !    43.0042 !     0.0    !
 !  1.4999+04 !     1.0000 !    42.4158 !     0.0    !
 !  1.6363+04 !     1.0000 !    41.8273 !     0.0    !
 !  1.7726+04 !     1.0000 !    41.2389 !     0.0    !
 !  1.9090+04 !     1.0000 !    40.6505 !     0.0    !
 !------------+------------+------------+------------!
 !  2.0454+04 !     1.0000 !    40.0620 !     0.0    !
 !  2.1817+04 !     1.0000 !    39.4736 !     0.0    !
 !  2.3181+04 !     1.0000 !    38.8853 !     0.0    !
 !  2.4544+04 !     1.0000 !    38.2969 !     0.0    !
 !  2.5908+04 !     1.0000 !    37.7085 !     0.0    !
 !------------+------------+------------+------------!
 !  2.7271+04 !     1.0000 !    37.1202 !     0.0    !
 !  2.8635+04 !     1.0000 !    36.5319 !     0.0    !
 -----------------------------------------------------

 HEATX HOT-TQCUR UP-CO-02 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
```

```
  PRESSURE DROP:          0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    11.7000 !   236.2172 !     1.0000 !
!  1363.5739 !    11.7000 !   226.8587 !     1.0000 !
!  2727.1478 !    11.7000 !   217.4864 !     1.0000 !
!  4090.7217 !    11.7000 !   208.1009 !     1.0000 !
!  5454.2957 !    11.7000 !   198.7028 !     1.0000 !
!------------+------------+------------+------------!
!  6817.8696 !    11.7000 !   189.2927 !     1.0000 !
!  8181.4435 !    11.7000 !   179.8714 !     1.0000 !
!  9545.0174 !    11.7000 !   170.4396 !     1.0000 !
!  1.0909+04 !    11.7000 !   160.9980 !     1.0000 !
!  1.2272+04 !    11.7000 !   151.5476 !     1.0000 !
!------------+------------+------------+------------!
!  1.3636+04 !    11.7000 !   142.0893 !     1.0000 !
!  1.4999+04 !    11.7000 !   132.6240 !     1.0000 !
!  1.6363+04 !    11.7000 !   123.1527 !     1.0000 !
!  1.7726+04 !    11.7000 !   113.6767 !     1.0000 !
!  1.9090+04 !    11.7000 !   104.1968 !     1.0000 !
!------------+------------+------------+------------!
!  2.0454+04 !    11.7000 !    94.7145 !     1.0000 !
!  2.1817+04 !    11.7000 !    85.2310 !     1.0000 !
!  2.3181+04 !    11.7000 !    75.7476 !     1.0000 !
!  2.4544+04 !    11.7000 !    66.2658 !     1.0000 !
!  2.5908+04 !    11.7000 !    56.7871 !     1.0000 !
!------------+------------+------------+------------!
!  2.7271+04 !    11.7000 !    47.3130 !     1.0000 !
!  2.8635+04 !    11.7000 !    37.8454 !     1.0000 !
-----------------------------------------------------

BLOCK:  UP-CO-03 MODEL: HEATX
-----------------------------
  HOT SIDE:
  ---------
  INLET STREAM:             13
  OUTLET STREAM:            14
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
  COLD SIDE:
  ----------
  INLET STREAM:             CW4
  OUTLET STREAM:            CW5
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
```

```
                                 IN              OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           975.256         975.256         0.00000
       MASS(KG/HR   )           18766.5         18766.5         0.00000
       ENTHALPY(CAL/SEC )     -0.170273E+08   -0.170273E+08     0.00000

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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                      35.0000
     LMTD CORRECTION FACTOR                                1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP       BAR                     0.0345
     COLD SIDE PRESSURE DROP       BAR                     0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K         0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K         0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K         0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K         0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K         0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K         0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K         0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K         0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K         0.0203

                      ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   13        ----->|               HOT                  |-----> 14
```

```
   T=  6.4962D+02  |                                     |       T=
3.5000D+01
   P=  3.8966D+01  |                                     |       P=
3.8931D+01
   V=  1.0000D+00  |                                     |       V=
1.0000D+00
                   |                                     |
   CW5       <-----|               COLD                  |<----- CW4
   T=  2.9444D+01  |                                     |       T=
7.2222D+00
   P=  1.0000D+00  |                                     |       P=
1.0000D+00
   V=  0.0000D+00  |                                     |       V=
0.0000D+00
                   -------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY            CAL/SEC            113997.9145
     CALCULATED (REQUIRED) AREA      SQM                     2.9438
     ACTUAL EXCHANGER AREA           SQM                     2.9438
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     CAL/SEC-SQCM-K          0.0203
     UA (DIRTY)                      CAL/SEC-K             597.6554

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)                C                     190.7419
     NUMBER OF SHELLS IN SERIES                               1

   PRESSURE DROP:
     HOTSIDE, TOTAL                  BAR                     0.0345
     COLDSIDE, TOTAL                 BAR                     0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                       HOT
         -------------------------------------------------------------
         |                                                           |
  HOT IN |                             VAP                           |
HOT OUT
  ------> |                                                          |---
--->
   649.6  |                                                          |
35.0
          |                                                          |
  COLDOUT |                            LIQ                           |
COLDIN
  <------ |                                                          |<--
----
```

```
   29.4  |                                                           |
7.2
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     113997.915         2.9438     190.7419     0.0203
597.6554

 HEATX COLD-TQCU UP-CO-03 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !      1.0000 !     29.4444 !      0.0    !
 !  5428.4721 !      1.0000 !     28.3842 !      0.0    !
 !  1.0857+04 !      1.0000 !     27.3242 !      0.0    !
 !  1.6285+04 !      1.0000 !     26.2643 !      0.0    !
 !  2.1714+04 !      1.0000 !     25.2045 !      0.0    !
 !------------+------------+------------+------------!
 !  2.7142+04 !      1.0000 !     24.1450 !      0.0    !
 !  3.2571+04 !      1.0000 !     23.0856 !      0.0    !
 !  3.7999+04 !      1.0000 !     22.0264 !      0.0    !
 !  4.3428+04 !      1.0000 !     20.9674 !      0.0    !
 !  4.8856+04 !      1.0000 !     19.9086 !      0.0    !
 !------------+------------+------------+------------!
 !  5.4285+04 !      1.0000 !     18.8500 !      0.0    !
 !  5.9713+04 !      1.0000 !     17.7916 !      0.0    !
 !  6.5142+04 !      1.0000 !     16.7335 !      0.0    !
 !  7.0570+04 !      1.0000 !     15.6756 !      0.0    !
 !  7.5999+04 !      1.0000 !     14.6179 !      0.0    !
 !------------+------------+------------+------------!
 !  8.1427+04 !      1.0000 !     13.5606 !      0.0    !
 !  8.6856+04 !      1.0000 !     12.5034 !      0.0    !
 !  9.2284+04 !      1.0000 !     11.4466 !      0.0    !
 !  9.7712+04 !      1.0000 !     10.3901 !      0.0    !
 !  1.0314+05 !      1.0000 !      9.3338 !      0.0    !
 !------------+------------+------------+------------!
 !  1.0857+05 !      1.0000 !      8.2779 !      0.0    !
 !  1.1400+05 !      1.0000 !      7.2222 !      0.0    !
```

```
 -----------------------------------------------------

 HEATX HOT-TQCUR UP-CO-03 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    38.9658 !   649.6228 !     1.0000 !
 !  5428.4721 !    38.9658 !   621.9434 !     1.0000 !
 !  1.0857+04 !    38.9658 !   594.1472 !     1.0000 !
 !  1.6285+04 !    38.9658 !   566.2272 !     1.0000 !
 !  2.1714+04 !    38.9658 !   538.1757 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.7142+04 !    38.9658 !   509.9844 !     1.0000 !
 !  3.2571+04 !    38.9658 !   481.6443 !     1.0000 !
 !  3.7999+04 !    38.9658 !   453.1458 !     1.0000 !
 !  4.3428+04 !    38.9658 !   424.4788 !     1.0000 !
 !  4.8856+04 !    38.9658 !   395.6328 !     1.0000 !
 !------------+------------+------------+------------!
 !  5.4285+04 !    38.9658 !   366.5973 !     1.0000 !
 !  5.9713+04 !    38.9658 !   337.3621 !     1.0000 !
 !  6.5142+04 !    38.9658 !   307.9180 !     1.0000 !
 !  7.0570+04 !    38.9658 !   278.2580 !     1.0000 !
 !  7.5999+04 !    38.9658 !   248.3788 !     1.0000 !
 !------------+------------+------------+------------!
 !  8.1427+04 !    38.9658 !   218.2828 !     1.0000 !
 !  8.6856+04 !    38.9658 !   187.9816 !     1.0000 !
 !  9.2284+04 !    38.9658 !   157.4991 !     1.0000 !
 !  9.7712+04 !    38.9658 !   126.8775 !     1.0000 !
 !  1.0314+05 !    38.9658 !    96.1829 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.0857+05 !    38.9658 !    65.5132 !     1.0000 !
 !  1.1400+05 !    38.9658 !    35.0080 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  UP-CP-01 MODEL: COMPR
 -----------------------------
   INLET STREAM:          7
   OUTLET STREAM:         7A
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
```

```
         MOLE(KMOL/HR )            73.1600         73.1600         0.00000
         MASS(KG/HR   )            2118.72         2118.72         0.00000
         ENTHALPY(CAL/SEC )       -32.2948         24591.9        -1.00131

                    ***  CO2 EQUIVALENT SUMMARY ***
      FEED STREAMS CO2E            0.00000      KG/HR
      PRODUCT STREAMS CO2E         0.00000      KG/HR
      NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
      UTILITIES CO2E PRODUCTION    0.00000      KG/HR
      TOTAL CO2E PRODUCTION        0.00000      KG/HR

                         ***  INPUT DATA  ***

     ISENTROPIC CENTRIFUGAL COMPRESSOR
      OUTLET PRESSURE  BAR                                         3.42000
      ISENTROPIC EFFICIENCY                                        0.72000
      MECHANICAL EFFICIENCY                                        1.00000

                         ***  RESULTS  ***

      INDICATED  HORSEPOWER REQUIREMENT  KW                      103.097
      BRAKE      HORSEPOWER REQUIREMENT  KW                      103.097
      NET WORK REQUIRED                  KW                      103.097
      POWER LOSSES                       KW                        0.0
      ISENTROPIC HORSEPOWER REQUIREMENT  KW                       74.2295
      CALCULATED OUTLET TEMP  C                                  197.912
      ISENTROPIC TEMPERATURE  C                                  149.950
      EFFICIENCY (POLYTR/ISENTR) USED                              0.72000
      OUTLET VAPOR FRACTION                                        1.00000
      HEAD DEVELOPED,       M-KGF/KG                           12,861.3
      MECHANICAL EFFICIENCY USED                                   1.00000
      INLET HEAT CAPACITY RATIO                                    1.40242
      INLET VOLUMETRIC FLOW RATE , L/MIN                       30,221.5
      OUTLET VOLUMETRIC FLOW RATE, L/MIN                       13,983.5
      INLET  COMPRESSIBILITY FACTOR                                0.99984
      OUTLET COMPRESSIBILITY FACTOR                                1.00141
      AV. ISENT. VOL. EXPONENT                                     1.40015
      AV. ISENT. TEMP EXPONENT                                     1.39791
      AV. ACTUAL VOL. EXPONENT                                     1.59553
      AV. ACTUAL TEMP EXPONENT                                     1.59229

   BLOCK:  UP-CP-02 MODEL: COMPR
   -----------------------------
     INLET STREAM:          7B
     OUTLET STREAM:         7C
     PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT         RELATIVE
DIFF.
      TOTAL BALANCE
         MOLE(KMOL/HR )            73.1600         73.1600         0.00000
         MASS(KG/HR   )            2118.72         2118.72         0.00000
         ENTHALPY(CAL/SEC )        1715.93         30114.2        -0.943019
```

```
                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR

                         ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                    11.7000
    ISENTROPIC EFFICIENCY                                    0.72000
    MECHANICAL EFFICIENCY                                    1.00000

                         ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                  118.898
    BRAKE      HORSEPOWER REQUIREMENT  KW                  118.898
    NET WORK REQUIRED                  KW                  118.898
    POWER LOSSES                       KW                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                   85.6064
    CALCULATED OUTLET TEMP  C                              236.217
    ISENTROPIC TEMPERATURE  C                              181.461
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       M-KGF/KG                      14,832.5
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.40517
    INLET VOLUMETRIC FLOW RATE , L/MIN                  10,248.4
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                   4,435.97
    INLET  COMPRESSIBILITY FACTOR                            0.99985
    OUTLET COMPRESSIBILITY FACTOR                            1.00506
    AV. ISENT. VOL. EXPONENT                                 1.40440
    AV. ISENT. TEMP EXPONENT                                 1.39724
    AV. ACTUAL VOL. EXPONENT                                 1.59568
    AV. ACTUAL TEMP EXPONENT                                 1.58583

  BLOCK:  UP-CP-03 MODEL: COMPR
  -----------------------------
   INLET STREAM:          7D
   OUTLET STREAM:         8
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          73.1600         73.1600          0.00000
       MASS(KG/HR   )          2118.72         2118.72          0.00000
       ENTHALPY(CAL/SEC )      1479.11         28087.9        -0.947340

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
```

```
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                        40.0000
    ISENTROPIC EFFICIENCY                                        0.72000
    MECHANICAL EFFICIENCY                                        1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                      111.405
    BRAKE      HORSEPOWER REQUIREMENT  KW                      111.405
    NET WORK REQUIRED                  KW                      111.405
    POWER LOSSES                       KW                        0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                       80.2120
    CALCULATED OUTLET TEMP  C                                  222.905
    ISENTROPIC TEMPERATURE  C                                  172.329
    EFFICIENCY (POLYTR/ISENTR) USED                              0.72000
    OUTLET VAPOR FRACTION                                        1.00000
    HEAD DEVELOPED,       M-KGF/KG                          13,897.9
    MECHANICAL EFFICIENCY USED                                   1.00000
    INLET HEAT CAPACITY RATIO                                    1.41832
    INLET VOLUMETRIC FLOW RATE , L/MIN                       2,774.96
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                       1,279.26
    INLET  COMPRESSIBILITY FACTOR                                0.99965
    OUTLET COMPRESSIBILITY FACTOR                                1.01751
    AV. ISENT. VOL. EXPONENT                                     1.42616
    AV. ISENT. TEMP EXPONENT                                     1.39972
    AV. ACTUAL VOL. EXPONENT                                     1.62612
    AV. ACTUAL TEMP EXPONENT                                     1.58976

 BLOCK:  UP-CP-04 MODEL: COMPR
 ------------------------------
   INLET STREAM:           19
   OUTLET STREAM:          20
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            71.4222         71.4222          0.00000
       MASS(KG/HR   )            687.620         687.620        -
0.165334E-15
       ENTHALPY(CAL/SEC )        1372.66         1840.32        -0.254120

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
```

```
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                    40.0000
    ISENTROPIC EFFICIENCY                                    0.72000
    MECHANICAL EFFICIENCY                                    1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                    1.95801
    BRAKE      HORSEPOWER REQUIREMENT  KW                    1.95801
    NET WORK REQUIRED                  KW                    1.95801
    POWER LOSSES                       KW                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                    1.40977
    CALCULATED OUTLET TEMP  C                               38.3557
    ISENTROPIC TEMPERATURE  C                               37.4150
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       M-KGF/KG                         752.630
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.41657
    INLET VOLUMETRIC FLOW RATE , L/MIN                     798.958
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                     786.496
    INLET  COMPRESSIBILITY FACTOR                            1.01989
    OUTLET COMPRESSIBILITY FACTOR                            1.02043
    AV. ISENT. VOL. EXPONENT                                 1.44519
    AV. ISENT. TEMP EXPONENT                                 1.40503
    AV. ACTUAL VOL. EXPONENT                                 1.72261
    AV. ACTUAL TEMP EXPONENT                                 1.66651

 BLOCK:  UP-FH-01 MODEL: HEATER
 ------------------------------
   INLET STREAM:          8
   OUTLET STREAM:         9
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           73.1600         73.1600         0.00000
       MASS(KG/HR   )           2118.72         2118.72         0.00000
       ENTHALPY(CAL/SEC )       28087.9         77585.2       -0.637974

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

```
                         ***  INPUT DATA  ***
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED TEMPERATURE              C                       550.000
   SPECIFIED PRESSURE                 BAR                      40.0000
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000



                          ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                  550.00
   OUTLET PRESSURE       BAR                                40.000
   HEAT DUTY             CAL/SEC                            49497.




 BLOCK:  UP-HX-01 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:            11
   OUTLET STREAM:           15
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:            4
   OUTLET STREAM:           5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           1184.00         1184.00         0.00000
       MASS(KG/HR   )           18471.1         18471.1         0.00000
       ENTHALPY(CAL/SEC )     -0.120156E+08   -0.120156E+08   -
0.155019E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/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 OUTLET TEMP
     SPECIFIED VALUE                C                      590.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.3447
     COLD SIDE PRESSURE DROP        BAR                      0.3447

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   11         ----->|                HOT                 |-----> 15
   T=  8.0000D+02  |                                    |       T=
5.9845D+02
   P=  3.9311D+01  |                                    |       P=
3.8966D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   5          <-----|                COLD                |<----- 4
   T=  5.9000D+02  |                                    |       T=
3.8012D+02
   P=  3.9655D+01  |                                    |       P=
4.0000D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC             306825.9444
     CALCULATED (REQUIRED) AREA     SQM                      7.0577
     ACTUAL EXCHANGER AREA          SQM                      7.0577
```

```
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                     CAL/SEC-K             1432.8402

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)               C                      214.1383
     NUMBER OF SHELLS IN SERIES                               1

   PRESSURE DROP:
     HOTSIDE, TOTAL                 BAR                      0.3447
     COLDSIDE, TOTAL                BAR                      0.3447

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         --------------------------------------------------------------
         |                                                            |
 HOT IN  |                           VAP                              |
HOT OUT
 ------> |                                                            |---
--->
  800.0  |                                                            |
598.5
         |                                                            |
 COLDOUT |                           VAP                              |
COLDIN
 <------ |                                                            |<--
----
  590.0  |                                                            |
380.1
         |                                                            |
         --------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     306825.944         7.0577     214.1383     0.0203
1432.8402

 HEATX COLD-TQCU UP-HX-01 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         -0.3447     BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

 -----------------------------------------------------
```

```
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!    0.0     !    40.0000 !   590.1092 !     1.0000 !
!  1.4611+04 !    40.0000 !   580.2449 !     1.0000 !
!  2.9222+04 !    40.0000 !   570.3627 !     1.0000 !
!  4.3832+04 !    40.0000 !   560.4629 !     1.0000 !
!  5.8443+04 !    40.0000 !   550.5461 !     1.0000 !
!------------+------------+------------+------------!
!  7.3054+04 !    40.0000 !   540.6128 !     1.0000 !
!  8.7665+04 !    40.0000 !   530.6636 !     1.0000 !
!  1.0228+05 !    40.0000 !   520.6992 !     1.0000 !
!  1.1689+05 !    40.0000 !   510.7202 !     1.0000 !
!  1.3150+05 !    40.0000 !   500.7274 !     1.0000 !
!------------+------------+------------+------------!
!  1.4611+05 !    40.0000 !   490.7216 !     1.0000 !
!  1.6072+05 !    40.0000 !   480.7038 !     1.0000 !
!  1.7533+05 !    40.0000 !   470.6749 !     1.0000 !
!  1.8994+05 !    40.0000 !   460.6359 !     1.0000 !
!  2.0455+05 !    40.0000 !   450.5880 !     1.0000 !
!------------+------------+------------+------------!
!  2.1916+05 !    40.0000 !   440.5325 !     1.0000 !
!  2.3377+05 !    40.0000 !   430.4705 !     1.0000 !
!  2.4838+05 !    40.0000 !   420.4037 !     1.0000 !
!  2.6299+05 !    40.0000 !   410.3336 !     1.0000 !
!  2.7760+05 !    40.0000 !   400.2619 !     1.0000 !
!------------+------------+------------+------------!
!  2.9222+05 !    40.0000 !   390.1904 !     1.0000 !
!  3.0683+05 !    40.0000 !   380.1211 !     1.0000 !
-----------------------------------------------------

HEATX HOT-TQCUR UP-HX-01 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!    0.0     !    39.3105 !   800.0000 !     1.0000 !
!  1.4611+04 !    39.3105 !   790.6004 !     1.0000 !
!  2.9222+04 !    39.3105 !   781.1815 !     1.0000 !
!  4.3832+04 !    39.3105 !   771.7432 !     1.0000 !
!  5.8443+04 !    39.3105 !   762.2854 !     1.0000 !
```

```
 !-----------+-----------+-----------+-----------!
 !  7.3054+04 !    39.3105 !   752.8081 !     1.0000 !
 !  8.7665+04 !    39.3105 !   743.3111 !     1.0000 !
 !  1.0228+05 !    39.3105 !   733.7945 !     1.0000 !
 !  1.1689+05 !    39.3105 !   724.2582 !     1.0000 !
 !  1.3150+05 !    39.3105 !   714.7021 !     1.0000 !
 !-----------+-----------+-----------+-----------!
 !  1.4611+05 !    39.3105 !   705.1263 !     1.0000 !
 !  1.6072+05 !    39.3105 !   695.5307 !     1.0000 !
 !  1.7533+05 !    39.3105 !   685.9153 !     1.0000 !
 !  1.8994+05 !    39.3105 !   676.2801 !     1.0000 !
 !  2.0455+05 !    39.3105 !   666.6253 !     1.0000 !
 !-----------+-----------+-----------+-----------!
 !  2.1916+05 !    39.3105 !   656.9507 !     1.0000 !
 !  2.3377+05 !    39.3105 !   647.2565 !     1.0000 !
 !  2.4838+05 !    39.3105 !   637.5427 !     1.0000 !
 !  2.6299+05 !    39.3105 !   627.8094 !     1.0000 !
 !  2.7760+05 !    39.3105 !   618.0567 !     1.0000 !
 !-----------+-----------+-----------+-----------!
 !  2.9222+05 !    39.3105 !   608.2848 !     1.0000 !
 !  3.0683+05 !    39.3105 !   598.4937 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  UP-HX-02 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             12
   OUTLET STREAM:            13
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   COLD SIDE:
   ----------
   INLET STREAM:             5
   OUTLET STREAM:            6
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT         RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            648.722         648.722         0.00000
       MASS(KG/HR   )            12284.8         12284.8         0.00000
       ENTHALPY(CAL/SEC )      -0.701648E+07   -0.701648E+07     0.00000

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/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 OUTLET TEMP
     SPECIFIED VALUE               C                       610.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP       BAR                       0.3447
     COLD SIDE PRESSURE DROP       BAR                       0.3447

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   12        ----->|                HOT                 |-----> 13
   T=  8.0000D+02  |                                    |       T=
6.4962D+02
   P=  3.9311D+01  |                                    |       P=
3.8966D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   6         <-----|                COLD                |<----- 5
   T=  6.1000D+02  |                                    |       T=
5.9000D+02
   P=  3.9311D+01  |                                    |       P=
3.9655D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY          CAL/SEC             29852.2398
```

```
     CALCULATED (REQUIRED) AREA     SQM                         1.3071
     ACTUAL EXCHANGER AREA          SQM                         1.3071
     PER CENT OVER-DESIGN                                       0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K              0.0203
     UA (DIRTY)                     CAL/SEC-K                 265.3710

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                     1.0000
     LMTD (CORRECTED)               C                         112.4925
     NUMBER OF SHELLS IN SERIES                                   1

   PRESSURE DROP:
     HOTSIDE, TOTAL                 BAR                         0.3447
     COLDSIDE, TOTAL                BAR                         0.3447

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                            |
 HOT IN  |                           VAP                              |
HOT OUT
 ------> |                                                            |---
--->
  800.0  |                                                            |
649.6
         |                                                            |
 COLDOUT |                           VAP                              |
COLDIN
 <------ |                                                            |<--
----
  610.0  |                                                            |
590.0
         |                                                            |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      29852.240         1.3071     112.4925     0.0203
265.3710

 HEATX COLD-TQCU UP-HX-02 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         -0.3447     BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

```
-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    39.6553 !   610.1030 !     1.0000 !
!  1421.5352 !    39.6553 !   609.1475 !     1.0000 !
!  2843.0705 !    39.6553 !   608.1919 !     1.0000 !
!  4264.6057 !    39.6553 !   607.2360 !     1.0000 !
!  5686.1409 !    39.6553 !   606.2800 !     1.0000 !
!------------+------------+------------+------------!
!  7107.6761 !    39.6553 !   605.3238 !     1.0000 !
!  8529.2114 !    39.6553 !   604.3674 !     1.0000 !
!  9950.7466 !    39.6553 !   603.4108 !     1.0000 !
!  1.1372+04 !    39.6553 !   602.4540 !     1.0000 !
!  1.2794+04 !    39.6553 !   601.4971 !     1.0000 !
!------------+------------+------------+------------!
!  1.4215+04 !    39.6553 !   600.5400 !     1.0000 !
!  1.5637+04 !    39.6553 !   599.5827 !     1.0000 !
!  1.7058+04 !    39.6553 !   598.6252 !     1.0000 !
!  1.8480+04 !    39.6553 !   597.6676 !     1.0000 !
!  1.9901+04 !    39.6553 !   596.7097 !     1.0000 !
!------------+------------+------------+------------!
!  2.1323+04 !    39.6553 !   595.7517 !     1.0000 !
!  2.2745+04 !    39.6553 !   594.7936 !     1.0000 !
!  2.4166+04 !    39.6553 !   593.8352 !     1.0000 !
!  2.5588+04 !    39.6553 !   592.8767 !     1.0000 !
!  2.7009+04 !    39.6553 !   591.9180 !     1.0000 !
!------------+------------+------------+------------!
!  2.8431+04 !    39.6553 !   590.9591 !     1.0000 !
!  2.9852+04 !    39.6553 !   590.0000 !     1.0000 !
-----------------------------------------------------

HEATX HOT-TQCUR UP-HX-02 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    39.3105 !   800.0000 !     1.0000 !
!  1421.5352 !    39.3105 !   792.9010 !     1.0000 !
!  2843.0705 !    39.3105 !   785.7962 !     1.0000 !
```

```
 !  4264.6057 !    39.3105 !   778.6856 !     1.0000 !
 !  5686.1409 !    39.3105 !   771.5692 !     1.0000 !
 !------------+------------+------------+------------!
 !  7107.6761 !    39.3105 !   764.4468 !     1.0000 !
 !  8529.2114 !    39.3105 !   757.3183 !     1.0000 !
 !  9950.7466 !    39.3105 !   750.1838 !     1.0000 !
 !  1.1372+04 !    39.3105 !   743.0430 !     1.0000 !
 !  1.2794+04 !    39.3105 !   735.8960 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.4215+04 !    39.3105 !   728.7426 !     1.0000 !
 !  1.5637+04 !    39.3105 !   721.5827 !     1.0000 !
 !  1.7058+04 !    39.3105 !   714.4163 !     1.0000 !
 !  1.8480+04 !    39.3105 !   707.2433 !     1.0000 !
 !  1.9901+04 !    39.3105 !   700.0635 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.1323+04 !    39.3105 !   692.8769 !     1.0000 !
 !  2.2745+04 !    39.3105 !   685.6834 !     1.0000 !
 !  2.4166+04 !    39.3105 !   678.4829 !     1.0000 !
 !  2.5588+04 !    39.3105 !   671.2753 !     1.0000 !
 !  2.7009+04 !    39.3105 !   664.0604 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.8431+04 !    39.3105 !   656.8382 !     1.0000 !
 !  2.9852+04 !    39.3105 !   649.6086 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  UP-MX-01 MODEL: MIXER
 -----------------------------
   INLET STREAMS:         3           20
   OUTLET STREAM:         4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           563.122         563.122         0.00000
       MASS(KG/HR   )           9545.73         9545.73       -
0.190555E-15
       ENTHALPY(CAL/SEC )      -0.746717E+07   -0.746717E+07
0.124722E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                         ***  INPUT DATA  ***
   ONE    PHASE      FLASH   SPECIFIED PHASE IS  VAPOR
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE                                       0.000100000
   OUTLET PRESSURE   BAR                                     40.0000
```

```
 BLOCK:  UP-MX-02 MODEL: MIXER
 -----------------------------
   INLET STREAMS:         6           9
   OUTLET STREAM:         10A
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            636.282         636.282         0.00000
       MASS(KG/HR   )            11664.4         11664.4
0.311886E-15
       ENTHALPY(CAL/SEC )      -0.705290E+07   -0.705290E+07   -
0.132048E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  UP-MX-03 MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          10A
   OUTLET STREAM:         10B
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(KMOL/HR )         636.282       620.882      -15.4000
0.00000
   MASS(KG/HR   )         11664.4       11664.4
0.00000
   ENTHALPY(CAL/SEC )   -0.705290E+07 -0.723256E+07
0.248403E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
```

```
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     WATER      1.00    HYDROGEN  -1.00    OXYGEN   -0.500


   REACTION EXTENT SPECS: NUMBER=    1
     REACTION #   1: EXTENT=   30.80     KMOL/HR




   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED TEMPERATURE C                                 800.000
   SPECIFIED PRESSURE    BAR                                39.3105
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO

                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                    800.00
   OUTLET PRESSURE       BAR                                  39.311
   HEAT DUTY             CAL/SEC                            -0.17966E+06



 BLOCK:  UP-PM-01 MODEL: PUMP
 ----------------------------
   INLET STREAM:          1
   OUTLET STREAM:         2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           491.700         491.700         0.00000
       MASS(KG/HR   )           8858.11         8858.11         0.00000
       ENTHALPY(CAL/SEC )     -0.942335E+07   -0.941751E+07   -
0.619183E-03

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR                                   40.0000
    DRIVER EFFICIENCY                                       1.00000
```

```
    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                            30
    TOLERANCE                                               0.000100000

                           ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  L/MIN                           153.615
    PRESSURE CHANGE  BAR                                   39.0000
    NPSH AVAILABLE   M-KGF/KG                              10.3610
    FLUID POWER  KW                                         9.98495
    BRAKE POWER  KW                                        24.4291
    ELECTRICITY  KW                                        24.4291
    PUMP EFFICIENCY USED                                    0.40873
    NET WORK REQUIRED  KW                                  24.4291
    HEAD DEVELOPED M-KGF/KG                               413.796

 BLOCK:  UP-SE-01 MODEL: SEP
 ---------------------------
   INLET STREAM:          16
   OUTLET STREAMS:        18          17
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE


***********************************************************************
     *
*
     *     SUM OF SPLITS SPECIFIED IS ILLEGAL
*
     *
*

***********************************************************************


                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            620.882         620.882
0.577485E-06
       MASS(KG/HR   )            8925.35         8925.35
0.990596E-07
       ENTHALPY(CAL/SEC )      -0.670452E+07   -0.670542E+07
0.134095E-03

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

```
                        ***  INPUT DATA  ***

   FLASH SPECS FOR STREAM 18
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  VAPOR
   SPECIFIED PRESSURE    BAR                                   38.9313
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE                                        0.000100000

   FLASH SPECS FOR STREAM 17
   ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  LIQUID
   PRESSURE DROP         BAR                                    0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE                                        0.000100000

   MOLE-FLOW (KMOL/HR )
     SUBSTREAM= MIXED
       STREAM= 18        CPT= WATER     FLOW=              0.0
                              HYDROGEN                   232.800
                              NITROGEN                    77.6000
                              OXYGEN                       0.0
                              ARGON                        0.90000


                         ***  RESULTS  ***

   HEAT DUTY             CAL/SEC                                -899.15

  COMPONENT = WATER
    STREAM     SUBSTREAM    SPLIT FRACTION
    17         MIXED                 1.00000

  COMPONENT = HYDROGEN
    STREAM     SUBSTREAM    SPLIT FRACTION
    18         MIXED                 1.00000

  COMPONENT = NITROGEN
    STREAM     SUBSTREAM    SPLIT FRACTION
    18         MIXED                 0.99918
    17         MIXED                 0.00082406

  COMPONENT = ARGON
    STREAM     SUBSTREAM    SPLIT FRACTION
    18         MIXED                 1.00000

 BLOCK:  UP-SP-01 MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          18
   OUTLET STREAMS:        19          21
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE
DIFF.
```

```
    TOTAL BALANCE
       MOLE(KMOL/HR )             269.518          269.518          0.00000
       MASS(KG/HR   )             2594.79          2594.79          0.00000
       ENTHALPY(CAL/SEC )         5179.84          5179.84          0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR

                          ***  INPUT DATA  ***

  FRACTION OF FLOW                 STRM=19       FRAC=         0.26500

                           ***  RESULTS  ***

  STREAM= 19             SPLIT=          0.26500     KEY=  0    STREAM-
ORDER=   1
          21                             0.73500           0
2
```

B.1.5 SOEC Stream Summary

```
 1 10A 10B 11 12
 ---------------

 STREAM ID                1          10A        10B        11         12
 FROM :                   ----       UP-MX-02   UP-MX-03   SOEC2      
SOEC2
 TO   :                   UP-PM-01   UP-MX-03   SOEC       UP-HX-01   UP-
HX-02

 SUBSTREAM: MIXED
 PHASE:                   LIQUID     VAPOR      VAPOR      VAPOR      
VAPOR
 COMPONENTS: KMOL/HR
   WATER                 491.7000   491.7000   522.5000   351.3000      0.0
   HYDROGEN                0.0       50.6203    19.8203   191.0203      0.0
   NITROGEN                0.0       77.6640    77.6640    77.6640      0.0
   OXYGEN                  0.0       15.4000     0.0        0.0       
85.6000
   ARGON                   0.0        0.8980     0.8980     0.8980      0.0
 TOTAL FLOW:
   KMOL/HR               491.7000   636.2822   620.8822   620.8822   
85.6000
   KG/HR                8858.1132  1.1664+04  1.1664+04  8925.3523   
2739.0973
   L/MIN                 153.6146  1.9539+04  2.3484+04  2.3589+04   
3269.1917
 STATE VARIABLES:
   TEMP   C               25.0000   603.3524   800.0000   800.0000   
800.0000
   PRES   BAR              1.0000    39.3105    39.3105    39.3105   
39.3105
   VFRAC                   0.0        1.0000     1.0000     1.0000   
1.0000
   LFRAC                   1.0000     0.0        0.0        0.0        0.0
   SFRAC                   0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL             -6.8993+04 -3.9904+04 -4.1936+04 -2.6373+04   
6050.0777
   CAL/GM              -3829.7161 -2176.7382 -2232.1863 -1834.5980   
189.0720
   CAL/SEC             -9.4233+06 -7.0529+06 -7.2326+06 -4.5485+06   
1.4386+05
 ENTROPY:
   CAL/MOL-K             -38.9834    -5.1890    -4.3373    -1.1313   
2.4981
   CAL/GM-K               -2.1639    -0.2831    -0.2309 -7.8699-02   
7.8067-02
 DENSITY:
   MOL/CC               5.3348-02  5.4275-04  4.4064-04  4.3868-04   
4.3640-04
```

```
   GM/CC                  0.9611  9.9499-03  8.2783-03  6.3062-03
1.3964-02
  AVG MW                 18.0153    18.3322    18.7869    14.3753
31.9988

  13 14 15 16 17
  --------------

  STREAM ID              13         14         15         16         17
  FROM :                 UP-HX-02   UP-CO-03   UP-HX-01   UP-CD-01   UP-
SE-01
  TO   :                 UP-CO-03   ----       UP-CD-01   UP-SE-01   ----


  CONV. MAX. REL. ERR:     0.0        0.0     4.7370-06     0.0        0.0
  SUBSTREAM: MIXED
  PHASE:                 VAPOR      VAPOR      VAPOR      MIXED
LIQUID
  COMPONENTS: KMOL/HR
    WATER                  0.0        0.0      351.3000   351.3000
351.3000
    HYDROGEN               0.0        0.0      191.0203   191.0203     0.0
    NITROGEN               0.0        0.0       77.6640    77.6640
6.4000-02
    OXYGEN               85.6000    85.6000      0.0        0.0        0.0
    ARGON                  0.0        0.0        0.8980     0.8980     0.0
  TOTAL FLOW:
    KMOL/HR              85.6000    85.6000   620.8822   620.8822
351.3640
    KG/HR              2739.0973  2739.0973  8925.3523  8925.3523
6330.5607
    L/MIN              2838.9851   924.6971  1.9265+04  3129.5856
110.7025
  STATE VARIABLES:
    TEMP   C            649.6228    35.0000   598.4517    35.0000
35.0000
    PRES   BAR           38.9658    38.9313    38.9658    38.9313
38.9313
    VFRAC                  1.0000     1.0000     1.0000     0.4347     0.0
    LFRAC                  0.0        0.0        0.0        0.5653
1.0000
    SFRAC                  0.0        0.0        0.0        0.0        0.0
  ENTHALPY:
    CAL/MOL            4794.6097     0.3049 -2.8152+04 -3.8874+04 -
6.8755+04
    CAL/GM              149.8372  9.5286-03 -1958.3548 -2704.2386 -
3816.1179
    CAL/SEC            1.1401+05     7.2499 -4.8553+06 -6.7045+06 -
6.7106+06
  ENTROPY:
    CAL/MOL-K              1.2556    -7.2082    -2.9486   -24.2343   -
38.3942
    CAL/GM-K           3.9239-02    -0.2253    -0.2051    -1.6858    -
2.1310
```

```
 DENSITY:
   MOL/CC              5.0253-04  1.5428-03  5.3715-04  3.3065-03
5.2899-02
   GM/CC               1.6080-02  4.9369-02  7.7216-03  4.7532-02
0.9531
 AVG MW                  31.9988    31.9988    14.3753    14.3753
18.0171

 18 19 2 20 21
 -------------

 STREAM ID               18         19         2          20         21
 FROM :                  UP-SE-01   UP-SP-01   UP-PM-01   UP-CP-04   UP-
SP-01
 TO   :                  UP-SP-01   UP-CP-04   UP-BO-01   UP-MX-01   ----

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      VAPOR      LIQUID     VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   WATER                  0.0        0.0      491.7000     0.0        0.0
   HYDROGEN             191.0199    50.6203     0.0       50.6203
140.3996
   NITROGEN              77.6000    20.5640     0.0       20.5640
57.0360
   OXYGEN                 0.0        0.0        0.0        0.0        0.0
   ARGON                  0.8980     0.2380     0.0        0.2380
0.6600
 TOTAL FLOW:
   KMOL/HR              269.5179    71.4222   491.7000    71.4222
198.0956
   KG/HR               2594.7907   687.6195  8858.1132   687.6195
1907.1712
   L/MIN               3014.9374   798.9584   153.6654   786.4963
2215.9790
 STATE VARIABLES:
   TEMP   C              35.0000    35.0000    26.2138    38.3557
35.0000
   PRES   BAR            38.9313    38.9313    40.0000    40.0000
38.9313
   VFRAC                  1.0000     1.0000     0.0        1.0000
1.0000
   LFRAC                  0.0        0.0        1.0000     0.0        0.0
   SFRAC                  0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL               69.1881    69.1881 -6.8951+04    92.7604
69.1881
   CAL/GM                 7.1865     7.1865 -3827.3448     9.6349
7.1865
   CAL/SEC             5179.8437  1372.6586 -9.4175+06  1840.3216
3807.1851
 ENTROPY:
   CAL/MOL-K             -5.8222    -5.8222   -38.9164    -5.8010    -
5.8222
```

```
   CAL/GM-K              -0.6047    -0.6047    -2.1602    -0.6025    -
0.6047
 DENSITY:
   MOL/CC              1.4899-03  1.4899-03  5.3330-02  1.5135-03
1.4899-03
   GM/CC               1.4344-02  1.4344-02     0.9608  1.4571-02
1.4344-02
 AVG MW                   9.6275     9.6275    18.0153     9.6275
9.6275

 3 4 5 6 7
 ---------

 STREAM ID               3          4          5          6          7
 FROM :                  UP-BO-01   UP-MX-01   UP-HX-01   UP-HX-02   ----
 TO   :                  UP-MX-01   UP-HX-01   UP-HX-02   UP-MX-02   UP-
CP-01

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      VAPOR      VAPOR      VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   WATER                491.7000   491.7000   491.7000   491.7000      0.0
   HYDROGEN               0.0       50.6203    50.6203    50.6203      0.0
   NITROGEN               0.0       20.5640    20.5640    20.5640
57.1000
   OXYGEN                 0.0        0.0        0.0        0.0
15.4000
   ARGON                  0.0        0.2380     0.2380     0.2380
0.6600
 TOTAL FLOW:
   KMOL/HR              491.7000   563.1222   563.1222   563.1222
73.1600
   KG/HR               8858.1132  9545.7327  9545.7327  9545.7327
2118.7169
   L/MIN               1.1223+04  1.2184+04  1.6781+04  1.7349+04
3.0222+04
 STATE VARIABLES:
   TEMP   C             420.0000   380.1211   590.0000   610.0000
25.0000
   PRES   BAR            40.0000    40.0000    39.6553    39.3105
1.0000
   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:
   CAL/MOL            -5.4685+04 -4.7737+04 -4.5776+04 -4.5585+04    -
1.5891
   CAL/GM             -3035.4576 -2816.1067 -2700.3928 -2689.1346 -
5.4873-02
   CAL/SEC            -7.4690+06 -7.4672+06 -7.1603+06 -7.1305+06   -
32.2948
 ENTROPY:
```

```
   CAL/MOL-K             -11.1286    -9.5045    -6.8853    -6.6495
1.1410
   CAL/GM-K               -0.6177    -0.5607    -0.4062    -0.3923
3.9399-02
 DENSITY:
   MOL/CC               7.3021-04  7.7029-04  5.5928-04  5.4097-04
4.0347-05
   GM/CC                1.3155-02  1.3058-02  9.4805-03  9.1703-03
1.1684-03
 AVG MW                   18.0153    16.9514    16.9514    16.9514
28.9600

 7A 7B 7C 7D 8
 -------------

 STREAM ID                  7A         7B         7C         7D         8
 FROM :                     UP-CP-01   UP-CO-01   UP-CP-02   UP-CO-02   UP-
CP-03
 TO   :                     UP-CO-01   UP-CP-02   UP-CO-02   UP-CP-03   UP-
FH-01

 SUBSTREAM: MIXED
 PHASE:                     VAPOR      VAPOR      VAPOR      VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   WATER                      0.0        0.0        0.0        0.0        0.0
   HYDROGEN                   0.0        0.0        0.0        0.0        0.0
   NITROGEN                 57.1000    57.1000    57.1000    57.1000
57.1000
   OXYGEN                   15.4000    15.4000    15.4000    15.4000
15.4000
   ARGON                     0.6600     0.6600     0.6600     0.6600
0.6600
 TOTAL FLOW:
   KMOL/HR                  73.1600    73.1600    73.1600    73.1600
73.1600
   KG/HR                2118.7169  2118.7169  2118.7169  2118.7169
2118.7169
   L/MIN                1.3983+04  1.0248+04  4435.9706  2774.9582
1279.2606
 STATE VARIABLES:
   TEMP   C               197.9118    37.7778   236.2172    37.7778
222.9051
   PRES   BAR               3.4200     3.0753    11.7000    11.3553
40.0000
   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:
   CAL/MOL              1210.0985    84.4361  1481.8340    72.7828
1382.1251
   CAL/GM                 41.7851     2.9156    51.1682     2.5132
47.7252
```

```
   CAL/SEC             2.4592+04  1715.9285  3.0114+04  1479.1084
2.8088+04
 ENTROPY:
   CAL/MOL-K              1.9005    -0.8070  5.6172-03    -3.4379    -
2.6584
   CAL/GM-K            6.5626-02 -2.7865-02  1.9396-04    -0.1187 -
9.1795-02
 DENSITY:
   MOL/CC              8.7198-05  1.1898-04  2.7487-04  4.3941-04
9.5315-04
   GM/CC               2.5253-03  3.4456-03  7.9604-03  1.2725-02
2.7603-02
 AVG MW                  28.9600    28.9600    28.9600    28.9600
28.9600

 9 CW1 CW2 CW3 CW4
 -----------------

 STREAM ID               9          CW1        CW2        CW3        CW4
 FROM :                  UP-FH-01   ----       UP-CO-01   UP-CO-02   ----
 TO   :                  UP-MX-02   UP-CO-01   UP-CO-02   ----       UP-
CO-03

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      LIQUID     LIQUID     LIQUID
LIQUID
 COMPONENTS: KMOL/HR
   WATER                  0.0       403.0176   403.0176   403.0176
889.6555
   HYDROGEN               0.0        0.0        0.0        0.0        0.0
   NITROGEN             57.1000      0.0        0.0        0.0        0.0
   OXYGEN               15.4000      0.0        0.0        0.0        0.0
   ARGON                  0.6600      0.0        0.0        0.0        0.0
 TOTAL FLOW:
   KMOL/HR              73.1600   403.0176   403.0176   403.0176
889.6555
   KG/HR               2118.7169  7260.4752  7260.4752  7260.4752
1.6027+04
   L/MIN               2116.7436   126.0963   127.2374   128.7475
273.7279
 STATE VARIABLES:
   TEMP   C             550.0000    26.6667    36.5319    48.8889
7.2222
   PRES   BAR            40.0000     1.0000     1.0000     1.0000
1.0000
   VFRAC                  1.0000     0.0        0.0        0.0        0.0
   LFRAC                  0.0        1.0000     1.0000     1.0000
1.0000
   SFRAC                  0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL             3817.7504 -6.8959+04 -6.8755+04 -6.8499+04 -
6.9363+04
   CAL/GM               131.8282 -3827.7985 -3816.4558 -3802.2575 -
3850.2092
```

```
   CAL/SEC             7.7585+04 -7.7199+06 -7.6970+06 -7.6684+06 -
1.7141+07
 ENTROPY:
   CAL/MOL-K              1.1037   -38.8832   -38.3020   -37.5995   -
40.0894
   CAL/GM-K            3.8112-02    -2.1583    -2.1261    -2.0871    -
2.2253
 DENSITY:
   MOL/CC              5.7604-04  5.3269-02  5.2791-02  5.2172-02
5.4169-02
   GM/CC               1.6682-02     0.9596     0.9510     0.9399
0.9759
 AVG MW                  28.9600    18.0153    18.0153    18.0153
18.0153

 CW5 CW6 CW7 SOEC1
 -----------------

 STREAM ID               CW5        CW6        CW7        SOEC1
 FROM :                  UP-CO-03   ----       UP-CD-01   SOEC
 TO   :                  ----       UP-CD-01   ----       SOEC2

 SUBSTREAM: MIXED
 PHASE:                  LIQUID     LIQUID     LIQUID     VAPOR
 COMPONENTS: KMOL/HR
   WATER                889.6555  6392.4052  6392.4052   351.3000
   HYDROGEN               0.0        0.0        0.0      191.0203
   NITROGEN               0.0        0.0        0.0       77.6640
   OXYGEN                 0.0        0.0        0.0       85.6000
   ARGON                  0.0        0.0        0.0        0.8980
 TOTAL FLOW:
   KMOL/HR              889.6555  6392.4052  6392.4052   706.4822
   KG/HR               1.6027+04  1.1516+05  1.1516+05  1.1664+04
   L/MIN                279.0528  1928.2758  2010.1432  2.6866+04
 STATE VARIABLES:
   TEMP   C              29.4444   -17.7778    32.2222   800.0000
   PRES   BAR             1.0000     1.0000     1.0000    39.3105
   VFRAC                  0.0        0.0        0.0        1.0000
   LFRAC                  1.0000     1.0000     1.0000     0.0
   SFRAC                  0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL            -6.8901+04 -6.9885+04 -6.8844+04 -2.2443+04
   CAL/GM             -3824.6035 -3879.2179 -3821.4095 -1359.2898
   CAL/SEC            -1.7027+07 -1.2409+08 -1.2224+08 -4.4043+06
 ENTROPY:
   CAL/MOL-K            -38.7176   -41.7323   -38.5536  4.2610-02
   CAL/GM-K              -2.1492    -2.3165    -2.1400  2.5808-03
 DENSITY:
   MOL/CC              5.3135-02  5.5251-02  5.3001-02  4.3827-04
   GM/CC                  0.9572     0.9954     0.9548  7.2361-03
 AVG MW                  18.0153    18.0153    18.0153    16.5106
```

B.2.2 Ammonia Synthesis ASPEN Inputs

```
;
;Input Summary created by Aspen Plus Rel. 37.0 at 03:40:05 Mon Apr 20,
2020
;Directory C:\Users\dakotaw\Downloads  Filename
C:\Users\dakotaw\AppData\Local\Temp\~ap5ca7.txt
;


DYNAMICS
    DYNAMICS RESULTS=ON

IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar' SHORT-LENGTH=mm

DEF-STREAMS CONVEN ALL

SIM-OPTIONS MASS-BAL-CHE=YES FREE-WATER=YES

MODEL-OPTION

DATABANKS 'APV110 PURE37' / 'APV110 AQUEOUS' / 'APV110 SOLIDS' &
         / 'APV110 INORGANIC' / 'APESV110 AP-EOS' /  &
        'NISTV110 NIST-TRC' / NOASPENPCD

PROP-SOURCES 'APV110 PURE37' / 'APV110 AQUEOUS' /  &
        'APV110 SOLIDS' / 'APV110 INORGANIC' / 'APESV110 AP-EOS' &
         / 'NISTV110 NIST-TRC'

COMPONENTS
    AMMONIA H3N /
    N2 N2 /
    H2 H2 /
    ARGON AR /
    WATER H2O

SOLVE
    RUN-MODE MODE=SIM

FLOWSHEET
    BLOCK B4 IN=33 23 OUT=24
    BLOCK HB-RXN IN=28 OUT=29
    BLOCK HB-HXA-1 IN=31 25 OUT=32 26
    BLOCK HB-HXA-2 IN=29 27 OUT=30 28
    BLOCK HB-S-01 IN=24 OUT=25 34
    BLOCK HB-CP-03 IN=26 OUT=27
    BLOCK HB-S-02 IN=34 OUT=35 OUT
    BLOCK HB-CP-02 IN=35 OUT=36
    BLOCK B20 IN=36 OUT=PURGE 37
    BLOCK B21 IN=37 INPUT OUT=23
    BLOCK HB-HXA-3 IN=30 38 OUT=31 40
    BLOCK HB-HXA-4 IN=32 39 OUT=33 41
```

```
PROPERTIES SRK

STREAM 38
    SUBSTREAM MIXED TEMP=45. <F> PRES=1. MASS-FLOW=1754.
    MASS-FRAC WATER 1.

STREAM 39
    SUBSTREAM MIXED TEMP=45. <F> PRES=1. MASS-FLOW=23010.
    MASS-FRAC WATER 1.

STREAM 40
    SUBSTREAM MIXED TEMP=90. <F> PRES=1. MASS-FLOW=1754.
    MASS-FRAC WATER 1.

STREAM 41
    SUBSTREAM MIXED TEMP=90. <F> PRES=1. MASS-FLOW=23010.
    MASS-FRAC WATER 1.

STREAM INPUT
    SUBSTREAM MIXED TEMP=35. PRES=39.6 MOLE-FLOW=198.1
    MOLE-FLOW AMMONIA 0.0 / N2 57.04 / H2 140.4 / ARGON  &
        0.66 / WATER 0.

BLOCK B4 MIXER
    PARAM

BLOCK B21 MIXER
    PARAM

BLOCK B20 FSPLIT
    FRAC PURGE 0.02

BLOCK HB-S-01 FLASH2
    PARAM TEMP=30. PRES=39.6
    UTILITY UTILITY-ID=U-3

BLOCK HB-S-02 FLASH2
    PARAM TEMP=20.00000000 PRES=10.13250000
    UTILITY UTILITY-ID=U-3

BLOCK HB-HXA-1 HEATX
    PARAM INCR-COLD=60. CALC-TYPE=DESIGN PRES-HOT=35.46375000  &
        PRES-COLD=-5. <psi> MIN-TAPP=10.00000000  &
        CALC-METHOD=SHORTCUT
    FEEDS HOT=31 COLD=25
    OUTLETS-HOT 32
    OUTLETS-COLD 26
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK HB-HXA-2 HEATX
    PARAM T-COLD=225. PRES-COLD=-5. <psi>
    FEEDS HOT=29 COLD=27
```

```
    OUTLETS-HOT 30
    OUTLETS-COLD 28
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK HB-HXA-3 HEATX
    PARAM T-COLD=90. <F> TYPE=COUNTERCURRE PRES-HOT=-5. <psi>  &
        CALC-METHOD=SHORTCUT
    FEEDS HOT=30 COLD=38
    OUTLETS-HOT 31
    OUTLETS-COLD 40
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK HB-HXA-4 HEATX
    PARAM T-COLD=90. <F> PRES-HOT=-5. <psi>
    FEEDS HOT=32 COLD=39
    OUTLETS-HOT 33
    OUTLETS-COLD 41
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK HB-RXN RSTOIC
    PARAM TEMP=400.0000000 PRES=81.06000000
    STOIC 1 MIXED N2 -1. / H2 -3. / AMMONIA 2.
    CONV 1 MIXED H2 0.2
    UTILITY UTILITY-ID=U-3

BLOCK HB-CP-02 COMPR
    PARAM TYPE=ISENTROPIC PRES=39.6 SB-MAXIT=30 SB-TOL=0.0001
    UTILITY UTILITY-ID=U-3

BLOCK HB-CP-03 COMPR
    PARAM TYPE=ISENTROPIC PRES=81.06000000 SB-MAXIT=30  &
        SB-TOL=0.0001
    UTILITY UTILITY-ID=U-3

UTILITY U-1 GENERAL
    COST PRICE=1.000000000
    PARAM UTILITY-TYPE=WATER COOLING-VALU=1.000000000

UTILITY U-2 GENERAL
    DESCRIPTION  &
        "High Pressure Steam, Inlet Temp=250 C, Outlet Temp=249 C,
Pres=572 psia"
    COST ENERGY-PRICE=1.04670000E-8
    PARAM UTILITY-TYPE=STEAM TIN=250.0000000 TOUT=249.0000000  &
        VFRAC=1. VFR-OUT=0. CALOPT=FLASH MIN-TAPP=10.00000000  &
        CALCCO2=YES FACTORSOURCE="US-EPA-Rule-E9-5711" FUELSOURCE= &
        "Natural_gas" CO2FACTOR=2.34000000E-7 EFFICIENCY=0.85  &
        HTC=.1433075380
```

```
UTILITY U-3 GENERAL
    DESCRIPTION "Electrical Utility"
    COST ELEC-PRICE=.0775000000
    PARAM UTILITY-TYPE=ELECTRICITY CALCCO2=YES FACTORSOURCE= &
        "US-EPA-Rule-E9-5711" FUELSOURCE="Natural_gas"  &
        CO2FACTOR=2.34000000E-7 EFFICIENCY=0.58

UTILITY U-4 GENERAL
    DESCRIPTION "Cooling Water, Inlet Temp=20 C, Outlet Temp=25 C"
    COST ENERGY-PRICE=8.8760160E-10
    PARAM UTILITY-TYPE=WATER PRES=1.013250000  &
        PRES-OUT=1.013250000 TIN=20.00000000 TOUT=25.00000000  &
        CALOPT=FLASH MIN-TAPP=5.000000000 HTC=.0895672112

EO-CONV-OPTI

CONV-OPTIONS
    PARAM TOL=0.005

STREAM-REPOR MOLEFLOW MASSFLOW

PROPERTY-REP PCES
;
;
;
;
;
```

B.2.3 Ammonia Synthesis Full Summary

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 ASPEN PLUS IS A TRADEMARK OF           HOTLINE:
 ASPEN TECHNOLOGY, INC.                 U.S.A. 888/996-7100
 781/221-6400                           EUROPE (44) 1189-226555

 PLATFORM: WIN-X64                                      APRIL 20, 2020
 VERSION: 37.0   Build 395                              MONDAY
 INSTALLATION:                                          3:39:52 A.M.
```

TABLE OF CONTENTS

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: _3457zuo.inm

 OUTPUT PROBLEM DATA FILE NAME: _3457zuo
 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\AspenTech\Aspen Plus V11.0\Engine\\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET
```

```
                               FLOWSHEET SECTION

 FLOWSHEET CONNECTIVITY BY STREAMS
 ---------------------------------

   STREAM     SOURCE     DEST           STREAM     SOURCE     DEST
   INPUT      ----       B21            38         ----       HB-HXA-3
   39         ----       HB-HXA-4       24         B4         HB-S-01
   29         HB-RXN     HB-HXA-2       32         HB-HXA-1   HB-HXA-4
   26         HB-HXA-1   HB-CP-03       30         HB-HXA-2   HB-HXA-3
   28         HB-HXA-2   HB-RXN         25         HB-S-01    HB-HXA-1
   34         HB-S-01    HB-S-02        27         HB-CP-03   HB-HXA-2
   35         HB-S-02    HB-CP-02       OUT        HB-S-02    ----
   36         HB-CP-02   B20            PURGE      B20        ----
   37         B20        B21            23         B21        B4
   31         HB-HXA-3   HB-HXA-1       40         HB-HXA-3   ----
   33         HB-HXA-4   B4             41         HB-HXA-4   ----

 FLOWSHEET CONNECTIVITY BY BLOCKS
 --------------------------------

   BLOCK        INLETS                         OUTLETS
   B4           33 23                          24
   HB-RXN       28                             29
   HB-HXA-1     31 25                          32 26
   HB-HXA-2     29 27                          30 28
   HB-S-01      24                             25 34
   HB-CP-03     26                             27
   HB-S-02      34                             35 OUT
   HB-CP-02     35                             36
   B20          36                             PURGE 37
   B21          37 INPUT                       23
   HB-HXA-3     30 38                          31 40
   HB-HXA-4     32 39                          33 41

 CONVERGENCE STATUS SUMMARY
 --------------------------

   TEAR STREAM SUMMARY
   ===================


   STREAM    VARIABLE         MAXIMUM      MAX. ERR.    ABSOLUTE
CONV
   ID        ID               ERR/TOL      RELATIVE     ERROR       STAT
BLOCK
   ------    --------         --------     -------      ---------   ----
-----
   28       N2 MOLEFLOW        13.163      0.65813E-01  0.13621E-01  #
$OLVER05
```

```
   24       MASS ENTHALPY     0.68356     -0.34178E-02  0.19311E-04  #
$OLVER05
   31       N2 MOLEFLOW        10.562     -0.52808E-01  0.10814E-01  #
$OLVER05

   #  = CONVERGED
   *  = NOT CONVERGED

 CONVERGENCE BLOCK:  $OLVER05
 ----------------------------
     Tear Stream  :  28          24          31
     Tolerance used:  0.500D-02  0.500D-02  0.500D-02
     Trace molefrac:  0.500D-04  0.500D-04  0.500D-04
```

```
                               FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER05 (CONTINUED)
     MAXIT=   30 WAIT   1 ITERATIONS BEFORE ACCELERATING
     QMAX =   0.0     QMIN =  -5.0
     METHOD: WEGSTEIN      STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:    30


                          *** FINAL VALUES ***


     VAR#  TEAR STREAM VAR   STREAM    SUBSTREA COMPONEN UNIT
VALUE        PREV VALUE   ERR/TOL
     ----  ----------------  ------    -------- -------- ----         ---
--        ----------   -------
        1  TOTAL MOLEFLOW    28        MIXED             KMOL/HR
2337.7977    2259.7175    6.9106-02
        2  TOTAL MOLEFLOW    24        MIXED             KMOL/HR
2428.9364    2428.7642    1.4184-02
        3  TOTAL MOLEFLOW    31        MIXED             KMOL/HR
2166.1259    2227.4499   -5.5062-02
        4  MOLE-FLOW         28        MIXED    AMMONIA  KMOL/HR
807.8182     779.9406    7.1486-02
        5  MOLE-FLOW         28        MIXED    N2       KMOL/HR
794.0931     745.0587    3.1626-02
        6  MOLE-FLOW         28        MIXED    H2       KMOL/HR
702.0008     701.9366    1.8281-02
        7  MOLE-FLOW         28        MIXED    ARGON    KMOL/HR
33.8856      32.7816    6.7358
        8  MOLE-FLOW         28        MIXED    WATER    KMOL/HR
0.0          0.0          0.0
        9  PRESSURE          28        MIXED             BAR
80.7153      80.7153       0.0
       10  MASS ENTHALPY     28        MIXED             CAL/GM        -
139.3753    -141.3079    2.7353
       11  MOLE-FLOW         24        MIXED    AMMONIA  KMOL/HR
898.3425     898.2631    1.7674-02
       12  MOLE-FLOW         24        MIXED    N2       KMOL/HR
794.5430     794.4302    2.8409-02
       13  MOLE-FLOW         24        MIXED    H2       KMOL/HR
702.1252     702.1462   -6.0011-03
       14  MOLE-FLOW         24        MIXED    ARGON    KMOL/HR
33.9257      33.9247    6.4298-03
       15  MOLE-FLOW         24        MIXED    WATER    KMOL/HR
0.0          0.0          0.0
       16  PRESSURE          24        MIXED             BAR
35.1190      35.1190       0.0
       17  MASS ENTHALPY     24        MIXED             CAL/GM        -
135.4096    -134.9484      -0.6836
```

```
       18  MOLE-FLOW         31        MIXED    AMMONIA  KMOL/HR
873.5322     895.4369      -0.8925
       19  MOLE-FLOW         31        MIXED    N2       KMOL/HR
698.2629     737.1927      -0.5616
       20  MOLE-FLOW         31        MIXED    H2       KMOL/HR
561.5493     561.5867   -1.3303-02
       21  MOLE-FLOW         31        MIXED    ARGON    KMOL/HR
32.7816      33.2336      -0.7205
       22  MOLE-FLOW         31        MIXED    WATER    KMOL/HR
0.0          0.0          0.0
       23  PRESSURE          31        MIXED             BAR
80.7153      80.7153       0.0
       24  MASS ENTHALPY     31        MIXED             CAL/GM        -
100.0722     -97.0018      -0.3307

                          *** ITERATION HISTORY ***
```

```
                               FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER05 (CONTINUED)

     TEAR STREAMS AND TEAR VARIABLES:

     ITERATION MAX-ERR/TOL  VAR# STREAM ID VAR DESCRIPTION  SUBSTREA
COMPONEN ATTRIBUT ELEMENT
     --------- -----------  ---- --------- ---------------  -------- ----
---- -------- -------
          1       16.54       19 31        MOLE-FLO         MIXED    N2
          2       15.09       12 24        MOLE-FLO         MIXED    N2
          3       15.09        5 28        MOLE-FLO         MIXED    N2
          4       16.25       19 31        MOLE-FLO         MIXED    N2
          5       14.85       12 24        MOLE-FLO         MIXED    N2
          6       14.85        5 28        MOLE-FLO         MIXED    N2
          7       15.97       19 31        MOLE-FLO         MIXED    N2
          8       14.61       12 24        MOLE-FLO         MIXED    N2
          9       14.61        5 28        MOLE-FLO         MIXED    N2
         10       15.70       19 31        MOLE-FLO         MIXED    N2
         11       14.38       12 24        MOLE-FLO         MIXED    N2
         12       14.39        5 28        MOLE-FLO         MIXED    N2
         13       15.44       19 31        MOLE-FLO         MIXED    N2
         14       14.16       12 24        MOLE-FLO         MIXED    N2
         15       14.17        5 28        MOLE-FLO         MIXED    N2
         16       15.19       19 31        MOLE-FLO         MIXED    N2
         17       13.95       12 24        MOLE-FLO         MIXED    N2
         18       13.95        5 28        MOLE-FLO         MIXED    N2
         19       14.95       19 31        MOLE-FLO         MIXED    N2
         20       13.74       12 24        MOLE-FLO         MIXED    N2
         21       13.75        5 28        MOLE-FLO         MIXED    N2
         22       14.71       19 31        MOLE-FLO         MIXED    N2
         23       13.54       12 24        MOLE-FLO         MIXED    N2
         24       13.55        5 28        MOLE-FLO         MIXED    N2
         25       14.48       19 31        MOLE-FLO         MIXED    N2
         26       13.35       12 24        MOLE-FLO         MIXED    N2
         27       13.35        5 28        MOLE-FLO         MIXED    N2
         28       14.26       19 31        MOLE-FLO         MIXED    N2
         29       13.16       12 24        MOLE-FLO         MIXED    N2
         30       13.16        5 28        MOLE-FLO         MIXED    N2

 COMPUTATIONAL SEQUENCE
 ----------------------

 SEQUENCE USED WAS:
    U-3
    *$OLVER05 *HB-RXN HB-S-01 *HB-HXA-1 HB-HXA-4 HB-CP-03 HB-HXA-2 HB-
HXA-3
    |  HB-S-02 HB-CP-02 B20 B21 *B4
    (RETURN *$OLVER05)
    U-1 U-2 U-4
```

```
OVERALL FLOWSHEET BALANCE
-------------------------
```

```
                               FLOWSHEET SECTION

 OVERALL FLOWSHEET BALANCE (CONTINUED)

                      ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT       GENERATION   RELATIVE
DIFF.
   CONVENTIONAL COMPONENTS
           (KMOL/HR )
      AMMONIA             0.00000       87.5393       93.5916
0.691371E-01
      N2                  57.0400      0.267413E-01  -46.7958
0.179128
      H2                  140.400      0.693437E-02  -140.387
0.408834E-04
      ARGON              0.660000      0.692198E-02   0.00000
0.989512
      WATER               1374.61       1374.61       0.00000
0.00000
   TOTAL BALANCE
   MOLE(KMOL/HR )         1572.71       1462.19      -93.5916
0.107639E-01
   MASS(KG/HR   )         26671.3       26255.9
0.155748E-01
   ENTHALPY(CAL/SEC )   -0.261857E+08 -0.264110E+08
0.852834E-02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     3683.15      KG/HR
    TOTAL CO2E PRODUCTION         3683.15      KG/HR
```

```
                          PHYSICAL PROPERTIES SECTION

 COMPONENTS
 ----------

  ID       TYPE  ALIAS           NAME
   AMMONIA  C     H3N             AMMONIA
   N2       C     N2              NITROGEN
   H2       C     H2              HYDROGEN
   ARGON    C     AR              ARGON
   WATER    C     H2O             WATER
```

```
                                UTILITY SECTION

 UTILITY USAGE:  U-1       (WATER)
 ---------------------------------

  INPUT DATA:

    HEATING VALUE                        1.0000  CAL/GM
    PRICE                                1.0000  $/KG
    INDEX TYPE                             FUEL

  RESULT:

    HEATING VALUE                        1.0000  CAL/GM
    INDEXED PRICE                       MISSING  $/KG

  THIS UTILITY IS PURCHASED

  THIS UTILITY IS NOT USED BY ANY COST OR UOS BLOCKS
```

```
                                UTILITY SECTION

 UTILITY USAGE:  U-2       (STEAM)
 ---------------------------------

 HIGH PRESSURE STEAM, INLET TEMP=250 C, OUTLET TEMP=249 C, PRES=572 PSIA
  INPUT DATA:

    INLET TEMPERATURE                  250.0000  C
    OUTLET TEMPERATURE                 249.0000  C
    INLET VAPOR FRACTION                 1.0000
    OUTLET VAPOR FRACTION                0.0
    HEAT TRANSFER COEFFICIENT            0.1433  CAL/SEC-SQCM-K
    CO2 DATA SOURCE                         US-EPA-RULE-E9-5711
    CO2 FUEL SOURCE                         NATURAL_GAS
    CO2 EMISSION FACTOR               2.3400-07  KG/CAL
    THERMAL EFFICIENCY                   0.8500
    PRICE                             1.0467-08  $/CAL
    INDEX TYPE                             FUEL

  RESULT:

    HEATING VALUE                      410.6534  CAL/GM
    INDEXED PRICE                       MISSING  $/KG
    CO2 EMISSION FACTOR               2.3400-07  KG/CAL

  THIS UTILITY IS PURCHASED

  THIS UTILITY IS NOT USED BY ANY COST OR UOS BLOCKS
```

```
                                UTILITY SECTION

 UTILITY USAGE:  U-3       (ELECTRICITY)
 ---------------------------------------

 ELECTRICAL UTILITY
  INPUT DATA:

    CO2 DATA SOURCE                         US-EPA-RULE-E9-5711
    CO2 FUEL SOURCE                         NATURAL_GAS
    CO2 EMISSION FACTOR               2.3400-07  KG/CAL
    THERMAL EFFICIENCY                   0.5800
    PRICE                             7.7500-02  $/KWHR
    INDEX TYPE                             FUEL

  RESULT:

    INDEXED PRICE                     7.7500-02  $/KWHR
    CO2 EMISSION FACTOR               2.3400-07  KG/CAL
    TOTAL CO2 EMISSIONS               3683.1472  KG/HR

  THIS UTILITY IS PURCHASED

  USAGE:

  BLOCK ID  MODEL         DUTY              USAGE RATE        COST
CO2E EMISSIONS
                          CAL/SEC           KW                $/HR
KG/HR
  --------  ------------  ----------------  ----------------  -----------
-----  ----------------
  HB-S-01   FLASH2               1.4040+06         5878.4438
455.5794         2039.2502
  HB-S-02   FLASH2               1688.9115            7.0711
0.5480            2.4530
  HB-RXN    RSTOIC               6.1354+05         2568.7607
199.0790          891.1110
  HB-CP-02  COMPR                1159.9468            4.8565
0.3764            1.6847
  HB-CP-03  COMPR                5.1545+05         2158.0905
167.2520          748.6482
                          ----------------  ----------------  -----------
-----  ----------------
                  TOTAL:         2.5359+06         1.0617+04
822.8348         3683.1472
                          ================  ================
================  ================
```

```
                                UTILITY SECTION

 UTILITY USAGE:  U-4       (WATER)
 ---------------------------------

 COOLING WATER, INLET TEMP=20 C, OUTLET TEMP=25 C
  INPUT DATA:

     INLET TEMPERATURE                    20.0000  C
     OUTLET TEMPERATURE                   25.0000  C
     INLET PRESSURE                        1.0133  BAR
     OUTLET PRESSURE                       1.0133  BAR
     HEAT TRANSFER COEFFICIENT          8.9567-02  CAL/SEC-SQCM-K
     PRICE                              8.8760-10  $/CAL
     INDEX TYPE                              FUEL

  RESULT:

     COOLING VALUE                         4.9861  CAL/GM
     INDEXED PRICE                        MISSING  $/KG

  THIS UTILITY IS PURCHASED

  THIS UTILITY IS NOT USED BY ANY COST OR UOS BLOCKS
```

B.2.4 Ammonia Synthesis Block Summary

```
 BLOCK:  B4       MODEL: MIXER
 -----------------------------
   INLET STREAMS:         33          23
   OUTLET STREAM:         24
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           2428.94         2428.76
0.709150E-04
       MASS(KG/HR   )           40327.9         40323.3
0.111937E-03
       ENTHALPY(CAL/SEC )      -0.151688E+07   -0.151155E+07   -
0.351823E-02

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                         ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE                                    0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  B20      MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          36
   OUTLET STREAMS:        PURGE       37
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           3.45561         3.45561         0.00000
       MASS(KG/HR   )           60.9575         60.9575        -
0.233127E-15
       ENTHALPY(CAL/SEC )      -8022.40        -8022.40         0.00000

                     ***  CO2 EQUIVALENT SUMMARY ***
```

```
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                           ***  INPUT DATA  ***

  FRACTION OF FLOW                  STRM=PURGE    FRAC=         0.020000

                            ***  RESULTS  ***

  STREAM= PURGE          SPLIT=          0.020000    KEY=  0    STREAM-
ORDER=   1
         37                              0.98000           0
2

 BLOCK:  B21      MODEL: MIXER
 -----------------------------
   INLET STREAMS:         37          INPUT
   OUTLET STREAM:         23
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            201.486         201.486         0.00000
       MASS(KG/HR   )            1967.02         1967.02       -
0.115593E-15
       ENTHALPY(CAL/SEC )       -4053.81        -4053.81
0.673066E-15

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                           ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  HB-CP-02 MODEL: COMPR
 -----------------------------
   INLET STREAM:          35
   OUTLET STREAM:         36
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
```

```
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            3.45561         3.45561         0.00000
       MASS(KG/HR   )            60.9575         60.9575       -
0.116564E-15
       ENTHALPY(CAL/SEC )       -9182.34        -8022.40       -0.126324

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     1.68472      KG/HR
    TOTAL CO2E PRODUCTION         1.68472      KG/HR

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                    39.6000
    ISENTROPIC EFFICIENCY                                    0.72000
    MECHANICAL EFFICIENCY                                    1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                    4.85647
    BRAKE      HORSEPOWER REQUIREMENT  KW                    4.85647
    NET WORK REQUIRED                  KW                    4.85647
    POWER LOSSES                       KW                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                    3.49666
    CALCULATED OUTLET TEMP  C                              171.026
    ISENTROPIC TEMPERATURE  C                              138.310
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       M-KGF/KG                      21,057.5
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.41355
    INLET VOLUMETRIC FLOW RATE , L/MIN                     128.997
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                      50.2032
    INLET  COMPRESSIBILITY FACTOR                            0.93112
    OUTLET COMPRESSIBILITY FACTOR                            0.93470
    AV. ISENT. VOL. EXPONENT                                 1.30351
    AV. ISENT. TEMP EXPONENT                                 1.33106
    AV. ACTUAL VOL. EXPONENT                                 1.44439
    AV. ACTUAL TEMP EXPONENT                                 1.43854

                       ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                   U-3
  RATE OF CONSUMPTION                       4.8565  KW
  COST                                      0.3764  $/HR
```

```
  CO2 EQUIVALENT EMISSIONS                  1.6847  KG/HR

 BLOCK:  HB-CP-03 MODEL: COMPR
 -----------------------------
   INLET STREAM:          26
   OUTLET STREAM:         27
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          2337.80         2337.80         0.00000
       MASS(KG/HR   )          38771.7         38771.7         0.00000
       ENTHALPY(CAL/SEC )    -0.219547E+07   -0.168002E+07   -0.234779

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    748.648      KG/HR
    TOTAL CO2E PRODUCTION        748.648      KG/HR

                         ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR                                  81.0600
    ISENTROPIC EFFICIENCY                                  0.72000
    MECHANICAL EFFICIENCY                                  1.00000

                         ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW              2,158.09
    BRAKE      HORSEPOWER REQUIREMENT  KW              2,158.09
    NET WORK REQUIRED                  KW              2,158.09
    POWER LOSSES                       KW                  0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW              1,553.83
    CALCULATED OUTLET TEMP  C                            192.595
    ISENTROPIC TEMPERATURE  C                            166.431
    EFFICIENCY (POLYTR/ISENTR) USED                        0.72000
    OUTLET VAPOR FRACTION                                  1.00000
    HEAD DEVELOPED,       M-KGF/KG                    14,711.9
    MECHANICAL EFFICIENCY USED                             1.00000
    INLET HEAT CAPACITY RATIO                              1.41573
    INLET VOLUMETRIC FLOW RATE , L/MIN                29,474.6
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                18,736.7
    INLET  COMPRESSIBILITY FACTOR                          0.98351
    OUTLET COMPRESSIBILITY FACTOR                          1.00663
    AV. ISENT. VOL. EXPONENT                               1.40390
    AV. ISENT. TEMP EXPONENT                               1.35763
    AV. ACTUAL VOL. EXPONENT                               1.60051
    AV. ACTUAL TEMP EXPONENT                               1.52243
```

```
                    ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                      U-3
  RATE OF CONSUMPTION                       2158.0905  KW
  COST                                       167.2520  $/HR
  CO2 EQUIVALENT EMISSIONS                   748.6482  KG/HR

 BLOCK:  HB-HXA-1 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             31
   OUTLET STREAM:            32
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).
   COLD SIDE:
   ----------
   INLET STREAM:             25
   OUTLET STREAM:            26
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).


                   ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           4503.92         4565.25       -
0.134328E-01
       MASS(KG/HR   )           75650.8         77132.6       -
0.192104E-01
       ENTHALPY(CAL/SEC )     -0.354034E+07   -0.354881E+07
0.238712E-02

                   ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                       ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
```

```
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED COLD TEMP CHANGE
     SPECIFIED VALUE                C                       60.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE OUTLET PRESSURE      BAR                     35.4638
     COLD SIDE PRESSURE DROP        BAR                      0.3447

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   31         ----->|                HOT                |-----> 32
   T=  3.6480D+02  |                                    |       T=
3.0560D+02
   P=  8.0715D+01  |                                    |       P=
3.5464D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   26         <-----|                COLD               |<----- 25
   T=  9.0000D+01  |                                    |       T=
3.0000D+01
   P=  3.9255D+01  |                                    |       P=
3.9600D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC             319717.4714
     CALCULATED (REQUIRED) AREA     SQM                      5.6991
     ACTUAL EXCHANGER AREA          SQM                      5.6991
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
```

```
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                     CAL/SEC-K             1157.0230

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)               C                      276.3277
     NUMBER OF SHELLS IN SERIES                                1

   PRESSURE DROP:
     HOTSIDE, TOTAL                 BAR                     45.2515
     COLDSIDE, TOTAL                BAR                      0.3447

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |                                                           |---
--->
  364.8  |                                                           |
305.6
         |                                                           |
 COLDOUT |                           VAP                             |
COLDIN
 <------ |                                                           |<--
----
   90.0  |                                                           |
30.0
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     319717.471         5.6991     276.3277     0.0203
1157.0230

 HEATX COLD-TQCU HB-HXA-1 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         -0.3447     BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

 -----------------------------------------------------
 !  DUTY       !  PRES      !  TEMP      !  VFRAC     !
```

```
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!    0.0     !    39.6000 !    90.0869 !     1.0000 !
!  1.5225+04 !    39.6000 !    87.2080 !     1.0000 !
!  3.0449+04 !    39.6000 !    84.3298 !     1.0000 !
!  4.5674+04 !    39.6000 !    81.4525 !     1.0000 !
!  6.0899+04 !    39.6000 !    78.5762 !     1.0000 !
!------------+------------+------------+------------!
!  7.6123+04 !    39.6000 !    75.7010 !     1.0000 !
!  9.1348+04 !    39.6000 !    72.8271 !     1.0000 !
!  1.0657+05 !    39.6000 !    69.9547 !     1.0000 !
!  1.2180+05 !    39.6000 !    67.0839 !     1.0000 !
!  1.3702+05 !    39.6000 !    64.2148 !     1.0000 !
!------------+------------+------------+------------!
!  1.5225+05 !    39.6000 !    61.3478 !     1.0000 !
!  1.6747+05 !    39.6000 !    58.4828 !     1.0000 !
!  1.8270+05 !    39.6000 !    55.6203 !     1.0000 !
!  1.9792+05 !    39.6000 !    52.7603 !     1.0000 !
!  2.1314+05 !    39.6000 !    49.9030 !     1.0000 !
!------------+------------+------------+------------!
!  2.2837+05 !    39.6000 !    47.0487 !     1.0000 !
!  2.4359+05 !    39.6000 !    44.1977 !     1.0000 !
!  2.5882+05 !    39.6000 !    41.3501 !     1.0000 !
!  2.7404+05 !    39.6000 !    38.5063 !     1.0000 !
!  2.8927+05 !    39.6000 !    35.6665 !     1.0000 !
!------------+------------+------------+------------!
!  3.0449+05 !    39.6000 !    32.8309 !     1.0000 !
!  3.1972+05 !    39.6000 !    30.0000 !     1.0000 !
-----------------------------------------------------

HEATX HOT-TQCUR HB-HXA-1 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!    0.0     !    80.7153 !   367.0603 !     1.0000 !
!  1.5225+04 !    80.7153 !   364.3226 !     1.0000 !
!  3.0449+04 !    80.7153 !   361.5829 !     1.0000 !
!  4.5674+04 !    80.7153 !   358.8415 !     1.0000 !
```

```
 !  6.0899+04 !    80.7153 !   356.0981 !     1.0000 !
 !------------+------------+------------+------------!
 !  7.6123+04 !    80.7153 !   353.3530 !     1.0000 !
 !  9.1348+04 !    80.7153 !   350.6060 !     1.0000 !
 !  1.0657+05 !    80.7153 !   347.8572 !     1.0000 !
 !  1.2180+05 !    80.7153 !   345.1067 !     1.0000 !
 !  1.3702+05 !    80.7153 !   342.3543 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.5225+05 !    80.7153 !   339.6002 !     1.0000 !
 !  1.6747+05 !    80.7153 !   336.8444 !     1.0000 !
 !  1.8270+05 !    80.7153 !   334.0868 !     1.0000 !
 !  1.9792+05 !    80.7153 !   331.3275 !     1.0000 !
 !  2.1314+05 !    80.7153 !   328.5665 !     1.0000 !
 !------------+------------+------------+------------!
 !  2.2837+05 !    80.7153 !   325.8038 !     1.0000 !
 !  2.4359+05 !    80.7153 !   323.0395 !     1.0000 !
 !  2.5882+05 !    80.7153 !   320.2735 !     1.0000 !
 !  2.7404+05 !    80.7153 !   317.5058 !     1.0000 !
 !  2.8927+05 !    80.7153 !   314.7366 !     1.0000 !
 !------------+------------+------------+------------!
 !  3.0449+05 !    80.7153 !   311.9658 !     1.0000 !
 !  3.1972+05 !    80.7153 !   309.1934 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  HB-HXA-2 MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             29
   OUTLET STREAM:            30
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).
   COLD SIDE:
   ----------
   INLET STREAM:             27
   OUTLET STREAM:            28
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           4503.92         4503.92         0.00000
       MASS(KG/HR   )           75650.8         75650.8         0.00000
       ENTHALPY(CAL/SEC )      -0.251406E+07   -0.251406E+07
0.185223E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
```

```
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED COLD OUTLET TEMP
     SPECIFIED VALUE                C                      225.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.0000
     COLD SIDE PRESSURE DROP        BAR                      0.3447

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   29       ----->|                HOT                 |-----> 30
   T=  4.0000D+02  |                                    |       T=
3.6707D+02
   P=  8.1060D+01  |                                    |       P=
8.1060D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   28       <-----|                COLD                |<----- 27
   T=  2.2500D+02  |                                    |       T=
1.9260D+02
```

```
   P=  8.0715D+01  |                                     |       P=
8.1060D+01
   V=  1.0000D+00  |                                     |       V=
1.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY            CAL/SEC             178955.3759
     CALCULATED (REQUIRED) AREA      SQM                      5.0446
     ACTUAL EXCHANGER AREA           SQM                      5.0446
     PER CENT OVER-DESIGN                                     0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                      CAL/SEC-K             1024.1444

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                   1.0000
     LMTD (CORRECTED)                C                      174.7365
     NUMBER OF SHELLS IN SERIES                                1

   PRESSURE DROP:
     HOTSIDE, TOTAL                  BAR                      0.0000
     COLDSIDE, TOTAL                 BAR                      0.3447

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                    HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                          VAP                              |
HOT OUT
 ------> |                                                           |---
--->
  400.0  |                                                           |
367.1
         |                                                           |
 COLDOUT |                          VAP                              |
COLDIN
 <------ |                                                           |<--
----
  225.0  |                                                           |
192.6
         |                                                           |
         -------------------------------------------------------------
                                    COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
```

```
     1     178955.376         5.0446     174.7365     0.0203
1024.1444

 HEATX COLD-TQCU HB-HXA-2 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         -0.3447     BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    81.0600 !   225.0326 !     1.0000 !
 !  8521.6846 !    81.0600 !   223.4893 !     1.0000 !
 !  1.7043+04 !    81.0600 !   221.9457 !     1.0000 !
 !  2.5565+04 !    81.0600 !   220.4020 !     1.0000 !
 !  3.4087+04 !    81.0600 !   218.8581 !     1.0000 !
 !------------+------------+------------+------------!
 !  4.2608+04 !    81.0600 !   217.3141 !     1.0000 !
 !  5.1130+04 !    81.0600 !   215.7699 !     1.0000 !
 !  5.9652+04 !    81.0600 !   214.2256 !     1.0000 !
 !  6.8173+04 !    81.0600 !   212.6812 !     1.0000 !
 !  7.6695+04 !    81.0600 !   211.1366 !     1.0000 !
 !------------+------------+------------+------------!
 !  8.5217+04 !    81.0600 !   209.5919 !     1.0000 !
 !  9.3739+04 !    81.0600 !   208.0471 !     1.0000 !
 !  1.0226+05 !    81.0600 !   206.5022 !     1.0000 !
 !  1.1078+05 !    81.0600 !   204.9573 !     1.0000 !
 !  1.1930+05 !    81.0600 !   203.4122 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.2783+05 !    81.0600 !   201.8671 !     1.0000 !
 !  1.3635+05 !    81.0600 !   200.3219 !     1.0000 !
 !  1.4487+05 !    81.0600 !   198.7766 !     1.0000 !
 !  1.5339+05 !    81.0600 !   197.2314 !     1.0000 !
 !  1.6191+05 !    81.0600 !   195.6860 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.7043+05 !    81.0600 !   194.1407 !     1.0000 !
 !  1.7896+05 !    81.0600 !   192.5954 !     1.0000 !
 -----------------------------------------------------

 HEATX HOT-TQCUR HB-HXA-2 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).
```

```
-----------------------------------------------------
! DUTY       ! PRES       ! TEMP       ! VFRAC      !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
! CAL/SEC    ! BAR        ! C          !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    81.0600 !   400.0000 !     1.0000 !
!  8521.6846 !    81.0600 !   398.4383 !     1.0000 !
!  1.7043+04 !    81.0600 !   396.8759 !     1.0000 !
!  2.5565+04 !    81.0600 !   395.3129 !     1.0000 !
!  3.4087+04 !    81.0600 !   393.7493 !     1.0000 !
!------------+------------+------------+------------!
!  4.2608+04 !    81.0600 !   392.1850 !     1.0000 !
!  5.1130+04 !    81.0600 !   390.6200 !     1.0000 !
!  5.9652+04 !    81.0600 !   389.0544 !     1.0000 !
!  6.8173+04 !    81.0600 !   387.4881 !     1.0000 !
!  7.6695+04 !    81.0600 !   385.9212 !     1.0000 !
!------------+------------+------------+------------!
!  8.5217+04 !    81.0600 !   384.3537 !     1.0000 !
!  9.3739+04 !    81.0600 !   382.7855 !     1.0000 !
!  1.0226+05 !    81.0600 !   381.2166 !     1.0000 !
!  1.1078+05 !    81.0600 !   379.6472 !     1.0000 !
!  1.1930+05 !    81.0600 !   378.0771 !     1.0000 !
!------------+------------+------------+------------!
!  1.2783+05 !    81.0600 !   376.5063 !     1.0000 !
!  1.3635+05 !    81.0600 !   374.9349 !     1.0000 !
!  1.4487+05 !    81.0600 !   373.3629 !     1.0000 !
!  1.5339+05 !    81.0600 !   371.7903 !     1.0000 !
!  1.6191+05 !    81.0600 !   370.2170 !     1.0000 !
!------------+------------+------------+------------!
!  1.7043+05 !    81.0600 !   368.6431 !     1.0000 !
!  1.7896+05 !    81.0600 !   367.0686 !     1.0000 !
-----------------------------------------------------

BLOCK:  HB-HXA-3 MODEL: HEATX
-----------------------------
  HOT SIDE:
  ---------
  INLET STREAM:             30
  OUTLET STREAM:            31
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).
  COLD SIDE:
  ----------
  INLET STREAM:             38
  OUTLET STREAM:            40
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).
```

```
                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            2263.49         2263.49         0.00000
       MASS(KG/HR   )            38633.1         38633.1         0.00000
       ENTHALPY(CAL/SEC )      -0.286797E+07   -0.286797E+07
0.324732E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED COLD OUTLET TEMP
     SPECIFIED VALUE                C                       32.2222
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                      0.3447
     COLD SIDE PRESSURE DROP        BAR                      0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
```

```
                   --------------------------------------
                   |                                     |
   30        ----->|                HOT                  |-----> 31
   T=  3.6707D+02  |                                     |       T=
3.6480D+02
   P=  8.1060D+01  |                                     |       P=
8.0715D+01
   V=  1.0000D+00  |                                     |       V=
1.0000D+00
                   |                                     |
   40        <-----|                COLD                 |<----- 38
   T=  3.2222D+01  |                                     |       T=
7.2222D+00
   P=  1.0000D+00  |                                     |       P=
1.0000D+00
   V=  0.0000D+00  |                                     |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY          CAL/SEC               12156.9779
     CALCULATED (REQUIRED) AREA    SQM                       0.1730
     ACTUAL EXCHANGER AREA         SQM                       0.1730
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)   CAL/SEC-SQCM-K            0.0203
     UA (DIRTY)                    CAL/SEC-K                35.1267

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)              C                       346.0898
     NUMBER OF SHELLS IN SERIES                               1

   PRESSURE DROP:
     HOTSIDE, TOTAL                BAR                       0.3447
     COLDSIDE, TOTAL               BAR                       0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                     HOT
         -------------------------------------------------------------
         |                                                            |
 HOT IN  |                           VAP                              |
HOT OUT
 ------> |                                                            |---
--->
  367.1  |                                                            |
364.8
         |                                                            |
 COLDOUT |                           LIQ                              |
COLDIN
```

```
 <------ |                                                       |<--
----
   32.2  |                                                       |
7.2
         |                                                       |
         ---------------------------------------------------------
                                 COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1      12156.978         0.1730     346.0898     0.0203
35.1267

 HEATX COLD-TQCU HB-HXA-3 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !    0.0     !     1.0000 !    32.2222 !     0.0    !
 !  578.9037  !     1.0000 !    31.0299 !     0.0    !
 !  1157.8074 !     1.0000 !    29.8377 !     0.0    !
 !  1736.7111 !     1.0000 !    28.6455 !     0.0    !
 !  2315.6148 !     1.0000 !    27.4534 !     0.0    !
 !------------+------------+------------+------------!
 !  2894.5185 !     1.0000 !    26.2614 !     0.0    !
 !  3473.4223 !     1.0000 !    25.0695 !     0.0    !
 !  4052.3260 !     1.0000 !    23.8778 !     0.0    !
 !  4631.2297 !     1.0000 !    22.6862 !     0.0    !
 !  5210.1334 !     1.0000 !    21.4947 !     0.0    !
 !------------+------------+------------+------------!
 !  5789.0371 !     1.0000 !    20.3035 !     0.0    !
 !  6367.9408 !     1.0000 !    19.1125 !     0.0    !
 !  6946.8445 !     1.0000 !    17.9217 !     0.0    !
 !  7525.7482 !     1.0000 !    16.7312 !     0.0    !
 !  8104.6519 !     1.0000 !    15.5411 !     0.0    !
 !------------+------------+------------+------------!
 !  8683.5556 !     1.0000 !    14.3512 !     0.0    !
 !  9262.4593 !     1.0000 !    13.1618 !     0.0    !
 !  9841.3630 !     1.0000 !    11.9728 !     0.0    !
 !  1.0420+04 !     1.0000 !    10.7843 !     0.0    !
```

```
!  1.0999+04 !     1.0000 !     9.5964 !     0.0    !
!------------+------------+------------+------------!
!  1.1578+04 !     1.0000 !     8.4090 !     0.0    !
!  1.2157+04 !     1.0000 !     7.2222 !     0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR HB-HXA-3 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         BAR
  PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    81.0600 !   367.0686 !     1.0000 !
!   578.9037 !    81.0600 !   366.9616 !     1.0000 !
!  1157.8074 !    81.0600 !   366.8546 !     1.0000 !
!  1736.7111 !    81.0600 !   366.7476 !     1.0000 !
!  2315.6148 !    81.0600 !   366.6407 !     1.0000 !
!------------+------------+------------+------------!
!  2894.5185 !    81.0600 !   366.5337 !     1.0000 !
!  3473.4223 !    81.0600 !   366.4267 !     1.0000 !
!  4052.3260 !    81.0600 !   366.3197 !     1.0000 !
!  4631.2297 !    81.0600 !   366.2127 !     1.0000 !
!  5210.1334 !    81.0600 !   366.1056 !     1.0000 !
!------------+------------+------------+------------!
!  5789.0371 !    81.0600 !   365.9986 !     1.0000 !
!  6367.9408 !    81.0600 !   365.8916 !     1.0000 !
!  6946.8445 !    81.0600 !   365.7846 !     1.0000 !
!  7525.7482 !    81.0600 !   365.6776 !     1.0000 !
!  8104.6519 !    81.0600 !   365.5706 !     1.0000 !
!------------+------------+------------+------------!
!  8683.5556 !    81.0600 !   365.4635 !     1.0000 !
!  9262.4593 !    81.0600 !   365.3565 !     1.0000 !
!  9841.3630 !    81.0600 !   365.2495 !     1.0000 !
!  1.0420+04 !    81.0600 !   365.1425 !     1.0000 !
!  1.0999+04 !    81.0600 !   365.0354 !     1.0000 !
!------------+------------+------------+------------!
!  1.1578+04 !    81.0600 !   364.9284 !     1.0000 !
!  1.2157+04 !    81.0600 !   364.8213 !     1.0000 !
-----------------------------------------------------

BLOCK:  HB-HXA-4 MODEL: HEATX
-----------------------------
  HOT SIDE:
  ---------
```

```
   INLET STREAM:             32
   OUTLET STREAM:            33
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).
   COLD SIDE:
   ----------
   INLET STREAM:             39
   OUTLET STREAM:            41
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           3504.70         3504.70         0.00000
       MASS(KG/HR   )           61370.8         61370.8         0.00000
       ENTHALPY(CAL/SEC )      -0.256879E+08   -0.256879E+08   -
0.145021E-15

                   ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                       ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                 30
   CONVERGENCE TOLERANCE                                   0.000100000

   FLASH SPECS FOR COLD SIDE:
   TWO    PHASE      FLASH
   FREE WATER CONSIDERED
   MAXIMUM NO. ITERATIONS                                 30
   CONVERGENCE TOLERANCE                                   0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED COLD OUTLET TEMP
     SPECIFIED VALUE                C                     32.2222
     LMTD CORRECTION FACTOR                                1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE PRESSURE DROP        BAR                    0.3447
     COLD SIDE PRESSURE DROP        BAR                    0.0000

   HEAT TRANSFER COEFFICIENT SPECIFICATION:
```

```
     HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K           0.0203
     HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K           0.0203
     HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K           0.0203

                        ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   32        ----->|                HOT                 |-----> 33
   T=  3.0560D+02  |                                    |       T=
2.7567D+02
   P=  3.5464D+01  |                                    |       P=
3.5119D+01
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   41        <-----|                COLD                |<----- 39
   T=  3.2222D+01  |                                    |       T=
7.2222D+00
   P=  1.0000D+00  |                                    |       P=
1.0000D+00
   V=  0.0000D+00  |                                    |       V=
0.0000D+00
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           CAL/SEC             159482.3609
     CALCULATED (REQUIRED) AREA     SQM                      2.8997
     ACTUAL EXCHANGER AREA          SQM                      2.8997
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K           0.0203
     UA (DIRTY)                     CAL/SEC-K              588.7042

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)               C                      270.9040
     NUMBER OF SHELLS IN SERIES                               1

   PRESSURE DROP:
     HOTSIDE, TOTAL                 BAR                      0.3447
     COLDSIDE, TOTAL                BAR                      0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:
```

```
                                     HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |                                                           |---
--->
  305.6  |                                                           |
275.7
         |                                                           |
 COLDOUT |                           LIQ                             |
COLDIN
 <------ |                                                           |<--
----
   32.2  |                                                           |
7.2
         |                                                           |
         -------------------------------------------------------------
                                     COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              CAL/SEC         SQM         C         CAL/SEC-SQCM-K
CAL/SEC-K
     1     159482.361         2.8997     270.9040     0.0203
588.7042

 HEATX COLD-TQCU HB-HXA-4 TQCURV INLET
 -------------------------------------
   PRESSURE PROFILE:      CONSTANT2
   PRESSURE DROP:         0.0         BAR
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

 -----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  CAL/SEC   !  BAR       !  C         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !     1.0000 !    32.2222 !     0.0    !
 !  7594.3981 !     1.0000 !    31.0299 !     0.0    !
 !  1.5189+04 !     1.0000 !    29.8377 !     0.0    !
 !  2.2783+04 !     1.0000 !    28.6455 !     0.0    !
 !  3.0378+04 !     1.0000 !    27.4534 !     0.0    !
 !------------+------------+------------+------------!
 !  3.7972+04 !     1.0000 !    26.2614 !     0.0    !
 !  4.5566+04 !     1.0000 !    25.0695 !     0.0    !
 !  5.3161+04 !     1.0000 !    23.8778 !     0.0    !
```

```
!  6.0755+04 !     1.0000 !    22.6862 !     0.0    !
!  6.8350+04 !     1.0000 !    21.4947 !     0.0    !
!------------+------------+------------+------------!
!  7.5944+04 !     1.0000 !    20.3035 !     0.0    !
!  8.3538+04 !     1.0000 !    19.1125 !     0.0    !
!  9.1133+04 !     1.0000 !    17.9217 !     0.0    !
!  9.8727+04 !     1.0000 !    16.7312 !     0.0    !
!  1.0632+05 !     1.0000 !    15.5411 !     0.0    !
!------------+------------+------------+------------!
!  1.1392+05 !     1.0000 !    14.3512 !     0.0    !
!  1.2151+05 !     1.0000 !    13.1618 !     0.0    !
!  1.2910+05 !     1.0000 !    11.9728 !     0.0    !
!  1.3670+05 !     1.0000 !    10.7843 !     0.0    !
!  1.4429+05 !     1.0000 !     9.5964 !     0.0    !
!------------+------------+------------+------------!
!  1.5189+05 !     1.0000 !     8.4090 !     0.0    !
!  1.5948+05 !     1.0000 !     7.2222 !     0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR HB-HXA-4 TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0          BAR
  PROPERTY OPTION SET:   SRK        SOAVE-REDLICH-KWONG EQUATION OF STATE
  FREE WATER OPTION SET: SYSOP12    ASME STEAM TABLE
  SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  CAL/SEC   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    35.4637 !   305.5963 !     1.0000 !
!  7594.3981 !    35.4637 !   304.1792 !     1.0000 !
!  1.5189+04 !    35.4637 !   302.7614 !     1.0000 !
!  2.2783+04 !    35.4637 !   301.3430 !     1.0000 !
!  3.0378+04 !    35.4637 !   299.9240 !     1.0000 !
!------------+------------+------------+------------!
!  3.7972+04 !    35.4637 !   298.5043 !     1.0000 !
!  4.5566+04 !    35.4637 !   297.0841 !     1.0000 !
!  5.3161+04 !    35.4637 !   295.6632 !     1.0000 !
!  6.0755+04 !    35.4637 !   294.2417 !     1.0000 !
!  6.8350+04 !    35.4637 !   292.8196 !     1.0000 !
!------------+------------+------------+------------!
!  7.5944+04 !    35.4637 !   291.3969 !     1.0000 !
!  8.3538+04 !    35.4637 !   289.9736 !     1.0000 !
!  9.1133+04 !    35.4637 !   288.5497 !     1.0000 !
!  9.8727+04 !    35.4637 !   287.1251 !     1.0000 !
!  1.0632+05 !    35.4637 !   285.7000 !     1.0000 !
!------------+------------+------------+------------!
!  1.1392+05 !    35.4637 !   284.2742 !     1.0000 !
```

```
 !  1.2151+05 !    35.4637 !   282.8478 !     1.0000 !
 !  1.2910+05 !    35.4637 !   281.4209 !     1.0000 !
 !  1.3670+05 !    35.4637 !   279.9933 !     1.0000 !
 !  1.4429+05 !    35.4637 !   278.5651 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.5189+05 !    35.4637 !   277.1363 !     1.0000 !
 !  1.5948+05 !    35.4637 !   275.7069 !     1.0000 !
 -----------------------------------------------------

 BLOCK:  HB-RXN   MODEL: RSTOIC
 ------------------------------
   INLET STREAM:          28
   OUTLET STREAM:         29
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                      ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT       GENERATION   RELATIVE
DIFF.
   TOTAL BALANCE
   MOLE(KMOL/HR )         2337.80       2166.13      -93.5916
0.333991E-01
   MASS(KG/HR   )         38771.7       36879.1
0.488147E-01
   ENTHALPY(CAL/SEC )   -0.150106E+07  -834047.                  -
0.444362

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     891.111      KG/HR
    TOTAL CO2E PRODUCTION         891.111      KG/HR

                          ***  INPUT DATA  ***
   STOICHIOMETRY MATRIX:

    REACTION #   1:
     SUBSTREAM MIXED   :
     AMMONIA    2.00    N2        -1.00    H2        -3.00


   REACTION CONVERSION SPECS: NUMBER=    1
     REACTION #   1:
     SUBSTREAM:MIXED    KEY COMP:H2       CONV FRAC: 0.2000




   TWO    PHASE  TP  FLASH
   FREE WATER CONSIDERED
   SPECIFIED TEMPERATURE C                                   400.000
   SPECIFIED PRESSURE    BAR                                  81.0600
```

```
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE                                          0.000100000
   SIMULTANEOUS REACTIONS
   GENERATE COMBUSTION REACTIONS FOR FEED SPECIES          NO

                        ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                         400.00
   OUTLET PRESSURE       BAR                                       81.060
   HEAT DUTY             CAL/SEC                                  0.61354E+06
   VAPOR FRACTION                                                   1.0000
   1ST LIQUID/TOTAL LIQUID                                          1.0000

   REACTION EXTENTS:

      REACTION          REACTION
      NUMBER            EXTENT
                        KMOL/HR
      1                  46.796

   V-L1-L2 PHASE EQUILIBRIUM :

      COMP           F(I)      X1(I)     X2(I)     Y(I)      K1(I)
K2(I)
      AMMONIA       0.403     0.403      0.00     0.403
      N2            0.322     0.322      0.00     0.322
      H2            0.259     0.259      0.00     0.259
      ARGON         0.151E-01 0.151E-01  0.00     0.151E-01

                       ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                      U-3
  RATE OF CONSUMPTION                        2568.7607  KW
  COST                                        199.0790  $/HR
  CO2 EQUIVALENT EMISSIONS                    891.1110  KG/HR

 BLOCK:  HB-S-01  MODEL: FLASH2
 ------------------------------
   INLET STREAM:          24
   OUTLET VAPOR STREAM:   25
   OUTLET LIQUID STREAM:  34
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
   FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
   SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE
DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           2428.76         2428.76
0.187234E-15
       MASS(KG/HR   )           40323.3         40323.3       -
0.858535E-12
       ENTHALPY(CAL/SEC )      -0.151155E+07   -0.291559E+07    0.481564
```

```
                    ***  CO2 EQUIVALENT SUMMARY ***
     FEED STREAMS CO2E             0.00000      KG/HR
     PRODUCT STREAMS CO2E          0.00000      KG/HR
     NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
     UTILITIES CO2E PRODUCTION     2039.25      KG/HR
     TOTAL CO2E PRODUCTION         2039.25      KG/HR

                        ***  INPUT DATA  ***
    TWO    PHASE  TP  FLASH
    FREE WATER CONSIDERED
    SPECIFIED TEMPERATURE C                                 30.0000
    SPECIFIED PRESSURE    BAR                               39.6000
    MAXIMUM NO. ITERATIONS                                  30
    CONVERGENCE TOLERANCE                                    0.000100000

                         ***  RESULTS  ***
    OUTLET TEMPERATURE    C                                  30.000
    OUTLET PRESSURE       BAR                                39.600
    HEAT DUTY             CAL/SEC                           -0.14040E+07
    VAPOR FRACTION                                           0.96255
    1ST LIQUID/TOTAL LIQUID                                  1.0000

    V-L1-L2 PHASE EQUILIBRIUM :

       COMP           F(I)      X1(I)     X2(I)     Y(I)      K1(I)
K2(I)
       AMMONIA       0.370     0.994      0.00     0.346     0.348
       N2            0.327     0.370E-02  0.00     0.340      91.7
       H2            0.289     0.160E-02  0.00     0.300      188.
       ARGON         0.140E-01 0.429E-03  0.00     0.145E-01  33.8

                     ***  ASSOCIATED  UTILITIES  ***

   UTILITY ID FOR ELECTRICITY                   U-3
   RATE OF CONSUMPTION                     5878.4438  KW
   COST                                     455.5794  $/HR
   CO2 EQUIVALENT EMISSIONS                2039.2502  KG/HR

  BLOCK:  HB-S-02  MODEL: FLASH2
  ------------------------------
    INLET STREAM:          34
    OUTLET VAPOR STREAM:   35
    OUTLET LIQUID STREAM:  OUT
    PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF STATE
    FREE WATER OPTION SET: SYSOP12   ASME STEAM TABLE
    SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (SRK     ).

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE
DIFF.
     TOTAL BALANCE
        MOLE(KMOL/HR )          90.9664         90.9664         0.00000
        MASS(KG/HR   )          1551.62         1551.62
0.735774E-12
```

```
       ENTHALPY(CAL/SEC )       -400406.        -402095.
0.420028E-02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     2.45300      KG/HR
    TOTAL CO2E PRODUCTION         2.45300      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   FREE WATER CONSIDERED
   SPECIFIED TEMPERATURE C                                  20.0000
   SPECIFIED PRESSURE    BAR                                10.1325
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE                                     0.000100000

                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C                                    20.000
   OUTLET PRESSURE       BAR                                  10.133
   HEAT DUTY             CAL/SEC                             -1688.9
   VAPOR FRACTION                                            0.37988E-01
   1ST LIQUID/TOTAL LIQUID                                    1.0000

   V-L1-L2 PHASE EQUILIBRIUM :

      COMP           F(I)      X1(I)     X2(I)     Y(I)      K1(I)
K2(I)
      AMMONIA       0.994      1.00      0.00     0.858     0.858
      N2            0.370E-02 0.233E-03  0.00     0.916E-01  393.
      H2            0.160E-02 0.469E-04  0.00     0.409E-01  871.
      ARGON         0.429E-03 0.716E-04  0.00     0.948E-02  132.

                       ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                   U-3
  RATE OF CONSUMPTION                       7.0711  KW
  COST                                      0.5480  $/HR
  CO2 EQUIVALENT EMISSIONS                  2.4530  KG/HR
```

B.2.5 Ammonia Synthesis Stream Summary

```
 23 24 25 26 27
 --------------

 STREAM ID                23          24          25          26          27
 FROM :                   B21         B4          HB-S-01     HB-HXA-1    HB-
CP-03
 TO   :                   B4          HB-S-01     HB-HXA-1    HB-CP-03    HB-
HXA-2


 CONV. MAX. REL. ERR:      0.0    -3.4178-03     0.0         0.0         0.0
 SUBSTREAM: MIXED
 PHASE:                   VAPOR       VAPOR       VAPOR       VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   AMMONIA                 2.9056   898.2631   807.8182   807.8182
807.8182
   N2                     57.3503   794.4302   794.0931   794.0931
794.0931
   H2                    140.5385   702.1462   702.0008   702.0008
702.0008
   ARGON                   0.6921    33.9247    33.8856    33.8856
33.8856
   WATER                   0.0         0.0         0.0         0.0         0.0
 COMPONENTS: KG/HR
   AMMONIA                49.4840  1.5298+04  1.3758+04  1.3758+04
1.3758+04
   N2                   1606.5811  2.2255+04  2.2245+04  2.2245+04
2.2245+04
   H2                    283.3087  1415.4425  1415.1494  1415.1494
1415.1494
   ARGON                  27.6487  1355.2220  1353.6625  1353.6625
1353.6625
   WATER                   0.0         0.0         0.0         0.0         0.0
 TOTAL FLOW:
   KMOL/HR               201.4865  2428.7642  2337.7977  2337.7977
2337.7977
   KG/HR                1967.0225  4.0323+04  3.8772+04  3.8772+04
3.8772+04
   L/MIN                2233.1981  5.1244+04  2.3697+04  2.9475+04
1.8737+04
 STATE VARIABLES:
   TEMP   C               37.6133   258.8760    30.0000    90.0000
192.5954
   PRES   BAR             39.6000    35.1190    39.6000    39.2553
81.0600
   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:
```

```
   CAL/MOL              -72.4303 -2240.4691 -3873.1588 -3380.8224 -
2587.0749
   CAL/GM                -7.4192  -134.9484  -233.5378  -203.8516  -
155.9915
   CAL/SEC            -4053.8108 -1.5115+06 -2.5152+06 -2.1955+06 -
1.6800+06
 ENTROPY:
   CAL/MOL-K             -6.0069    -9.0337   -13.3370   -11.8379   -
11.3468
   CAL/GM-K              -0.6153    -0.5441    -0.8042    -0.7138    -
0.6842
 DENSITY:
   MOL/CC              1.5037-03  7.8994-04  1.6442-03  1.3219-03
2.0795-03
   GM/CC               1.4680-02  1.3115-02  2.7269-02  2.1924-02
3.4488-02
 AVG MW                   9.7626    16.6024    16.5847    16.5847
16.5847

 28 29 30 31 32
 --------------

 STREAM ID               28         29         30         31         32
 FROM :                  HB-HXA-2   HB-RXN     HB-HXA-2   HB-HXA-3   HB-
HXA-1
 TO   :                  HB-RXN     HB-HXA-2   HB-HXA-3   HB-HXA-1   HB-
HXA-4


 CONV. MAX. REL. ERR:  6.5813-02     0.0        0.0    -5.2808-02     0.0
 SUBSTREAM: MIXED
 PHASE:                  VAPOR      VAPOR      VAPOR      VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   AMMONIA              807.8182   873.5322   873.5322   873.5322
895.4369
   N2                   794.0931   698.2629   698.2629   698.2629
737.1927
   H2                   702.0008   561.5493   561.5493   561.5493
561.5867
   ARGON                 33.8856    32.7816    32.7816    32.7816
33.2336
   WATER                  0.0        0.0        0.0        0.0        0.0
 COMPONENTS: KG/HR
   AMMONIA             1.3758+04  1.4877+04  1.4877+04  1.4877+04
1.5250+04
   N2                  2.2245+04  1.9561+04  1.9561+04  1.9561+04
2.0651+04
   H2                  1415.1494  1132.0160  1132.0160  1132.0160
1132.0913
   ARGON               1353.6625  1309.5581  1309.5581  1309.5581
1327.6169
   WATER                  0.0        0.0        0.0        0.0        0.0
 TOTAL FLOW:
```

```
   KMOL/HR             2337.7977  2166.1259  2166.1259  2166.1259
2227.4499
   KG/HR               3.8772+04  3.6879+04  3.6879+04  3.6879+04
3.8361+04
   L/MIN               2.0227+04  2.5421+04  2.4149+04  2.4162+04
5.0674+04
 STATE VARIABLES:
   TEMP   C             225.0000   400.0000   367.0686   364.8045
305.5963
   PRES   BAR            80.7153    81.0600    81.0600    80.7153
35.4637
   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:
   CAL/MOL            -2311.4996 -1386.1469 -1683.5624 -1703.7667 -
2187.2785
   CAL/GM              -139.3753   -81.4166   -98.8855  -100.0722  -
127.0059
   CAL/SEC            -1.5011+06 -8.3405+05 -1.0130+06 -1.0252+06 -
1.3533+06
 ENTROPY:
   CAL/MOL-K            -10.7663    -9.4569    -9.9099    -9.9329    -
9.0742
   CAL/GM-K              -0.6492    -0.5555    -0.5821    -0.5834    -
0.5269
 DENSITY:
   MOL/CC              1.9263-03  1.4202-03  1.4950-03  1.4942-03
7.3260-04
   GM/CC               3.1947-02  2.4179-02  2.5453-02  2.5439-02
1.2617-02
 AVG MW                  16.5847    17.0254    17.0254    17.0254
17.2219

 33 34 35 36 37
 --------------

 STREAM ID               33         34         35         36         37
 FROM :                  HB-HXA-4   HB-S-01    HB-S-02    HB-CP-02   B20
 TO   :                  B4         HB-S-02    HB-CP-02   B20        B21

 SUBSTREAM: MIXED
 PHASE:                  VAPOR      LIQUID     VAPOR      VAPOR
VAPOR
 COMPONENTS: KMOL/HR
   AMMONIA              895.4369    90.4449     2.9649     2.9649
2.9056
   N2                   737.1927     0.3370     0.3166     0.3166
0.3103
   H2                   561.5867     0.1454     0.1413     0.1413
0.1385
   ARGON                 33.2336  3.9038-02  3.2772-02  3.2772-02
3.2116-02
```

```
   WATER                   0.0        0.0        0.0        0.0        0.0
 COMPONENTS: KG/HR
   AMMONIA              1.5250+04  1540.3279    50.4939    50.4939
49.4840
   N2                   2.0651+04     9.4413     8.8696     8.8696
8.6922
   H2                   1132.0913     0.2932     0.2849     0.2849
0.2792
   ARGON                1327.6169     1.5595     1.3092     1.3092
1.2830
   WATER                   0.0        0.0        0.0        0.0        0.0
 TOTAL FLOW:
   KMOL/HR              2227.4499    90.9664     3.4556     3.4556
3.3865
   KG/HR                3.8361+04  1551.6219    60.9575    60.9575
59.7383
   L/MIN                4.8457+04    46.4395   128.9968    50.2032
49.1991
 STATE VARIABLES:
   TEMP   C              275.6711    30.0000    20.0000   171.0260
171.0259
   PRES   BAR             35.1190    39.6000    10.1325    39.6000
39.6000
   VFRAC                   1.0000     0.0        1.0000     1.0000
1.0000
   LFRAC                   0.0        1.0000     0.0        0.0        0.0
   SFRAC                   0.0        0.0        0.0        0.0        0.0
 ENTHALPY:
   CAL/MOL             -2445.0335 -1.5846+04 -9566.0182 -8357.6044 -
8357.6044
   CAL/GM               -141.9727  -929.0029  -542.2868  -473.7832  -
473.7832
   CAL/SEC             -1.5128+06 -4.0041+05 -9182.3445 -8022.3977 -
7861.9497
 ENTROPY:
   CAL/MOL-K              -9.5120   -44.5577   -24.2168   -23.4255   -
23.4255
   CAL/GM-K               -0.5523    -2.6123    -1.3728    -1.3280    -
1.3280
 DENSITY:
   MOL/CC               7.6612-04  3.2647-02  4.4647-04  1.1472-03
1.1472-03
   GM/CC                1.3194-02     0.5569  7.8758-03  2.0237-02
2.0237-02
 AVG MW                   17.2219    17.0571    17.6401    17.6401
17.6401

 38 39 40 41 INPUT
 -----------------

 STREAM ID                38         39         40         41
INPUT
 FROM :                   ----       ----       HB-HXA-3   HB-HXA-4   ----
 TO   :                   HB-HXA-3   HB-HXA-4   ----       ----       B21
```

```
 SUBSTREAM: MIXED
 PHASE:                  LIQUID     LIQUID     LIQUID     LIQUID
VAPOR
 COMPONENTS: KMOL/HR
   AMMONIA                0.0        0.0        0.0        0.0        0.0
   N2                     0.0        0.0        0.0        0.0
57.0400
   H2                     0.0        0.0        0.0        0.0
140.4000
   ARGON                  0.0        0.0        0.0        0.0
0.6600
   WATER                 97.3618  1277.2491    97.3618  1277.2491     0.0
 COMPONENTS: KG/HR
   AMMONIA                0.0        0.0        0.0        0.0        0.0
   N2                     0.0        0.0        0.0        0.0
1597.8889
   H2                     0.0        0.0        0.0        0.0
283.0296
   ARGON                  0.0        0.0        0.0        0.0
26.3657
   WATER               1754.0000  2.3010+04  1754.0000  2.3010+04     0.0
 TOTAL FLOW:
   KMOL/HR               97.3618  1277.2491    97.3618  1277.2491
198.1000
   KG/HR               1754.0000  2.3010+04  1754.0000  2.3010+04
1907.2841
   L/MIN                 29.2341   383.5102    29.3784   385.4031
2179.3562
 STATE VARIABLES:
   TEMP   C               7.2222     7.2222    32.2222    32.2222
35.0000
   PRES   BAR             1.0000     1.0000     1.0000     1.0000
39.6000
   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:
   CAL/MOL            -6.8588+04 -6.8588+04 -6.8139+04 -6.8139+04
69.2039
   CAL/GM             -3807.2336 -3807.2336 -3782.2820 -3782.2820
7.1879
   CAL/SEC            -1.8550+06 -2.4335+07 -1.8428+06 -2.4175+07
3808.1389
 ENTROPY:
   CAL/MOL-K            -40.0894   -40.0894   -38.5536   -38.5536    -
5.8566
   CAL/GM-K              -2.2253    -2.2253    -2.1400    -2.1400    -
0.6083
 DENSITY:
   MOL/CC              5.5507-02  5.5507-02  5.5234-02  5.5234-02
1.5150-03
```

```
   GM/CC                  1.0000     1.0000     0.9951     0.9951
1.4586-02
 AVG MW                  18.0153    18.0153    18.0153    18.0153
9.6279

 OUT PURGE
 ---------

 STREAM ID               OUT        PURGE
 FROM :                  HB-S-02    B20
 TO   :                  ----       ----

 SUBSTREAM: MIXED
 PHASE:                  LIQUID     VAPOR
 COMPONENTS: KMOL/HR
   AMMONIA               87.4800  5.9298-02
   N2                  2.0409-02  6.3324-03
   H2                  4.1079-03  2.8265-03
   ARGON               6.2665-03  6.5543-04
   WATER                  0.0        0.0
 COMPONENTS: KG/HR
   AMMONIA             1489.8341     1.0099
   N2                     0.5717     0.1774
   H2                  8.2810-03  5.6979-03
   ARGON                  0.2503  2.6183-02
   WATER                  0.0        0.0
 TOTAL FLOW:
   KMOL/HR               87.5108  6.9112-02
   KG/HR               1490.6644     1.2191
   L/MIN                 43.3357     1.0041
 STATE VARIABLES:
   TEMP   C              20.0000   171.0259
   PRES   BAR            10.1325    39.6000
   VFRAC                  0.0        1.0000
   LFRAC                  1.0000     0.0
   SFRAC                  0.0        0.0
 ENTHALPY:
   CAL/MOL            -1.6164+04 -8357.6044
   CAL/GM              -948.8955  -473.7832
   CAL/SEC            -3.9291+05  -160.4480
 ENTROPY:
   CAL/MOL-K            -45.4736   -23.4255
   CAL/GM-K              -2.6696    -1.3280
 DENSITY:
   MOL/CC              3.3656-02  1.1472-03
   GM/CC                  0.5733  2.0237-02
 AVG MW                  17.0341    17.6401

 23
 --

 STREAM ID               23
 FROM :                  B21
 TO   :                  B4
```

```
SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA                2.9056
  N2                    57.3503
  H2                   140.5385
  ARGON                  0.6921
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA               49.4840
  N2                  1606.5811
  H2                   283.3087
  ARGON                 27.6487
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR              201.4865
  KG/HR               1967.0225
  L/MIN               2233.1981
STATE VARIABLES:
  TEMP   C              37.6133
  PRES   BAR            39.6000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL              -72.4303
  CAL/GM                -7.4192
  CAL/SEC            -4053.8108
ENTROPY:
  CAL/MOL-K             -6.0069
  CAL/GM-K              -0.6153
DENSITY:
  MOL/CC              1.5037-03
  GM/CC               1.4680-02
AVG MW                   9.7626

24
--

STREAM ID               24
FROM :                  B4
TO   :                  HB-S-01


CONV. MAX. REL. ERR: -3.4178-03
SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              898.2631
  N2                   794.4302
  H2                   702.1462
  ARGON                 33.9247
  WATER                  0.0
```

```
COMPONENTS: KG/HR
  AMMONIA             1.5298+04
  N2                  2.2255+04
  H2                  1415.4425
  ARGON               1355.2220
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             2428.7642
  KG/HR               4.0323+04
  L/MIN               5.1244+04
STATE VARIABLES:
  TEMP   C             258.8760
  PRES   BAR            35.1190
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -2240.4691
  CAL/GM              -134.9484
  CAL/SEC            -1.5115+06
ENTROPY:
  CAL/MOL-K             -9.0337
  CAL/GM-K              -0.5441
DENSITY:
  MOL/CC              7.8994-04
  GM/CC               1.3115-02
AVG MW                  16.6024

25
--

STREAM ID               25
FROM :                  HB-S-01
TO   :                  HB-HXA-1

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              807.8182
  N2                   794.0931
  H2                   702.0008
  ARGON                 33.8856
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1.3758+04
  N2                  2.2245+04
  H2                  1415.1494
  ARGON               1353.6625
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             2337.7977
  KG/HR               3.8772+04
  L/MIN               2.3697+04
STATE VARIABLES:
```

```
  TEMP   C              30.0000
  PRES   BAR            39.6000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -3873.1588
  CAL/GM              -233.5378
  CAL/SEC            -2.5152+06
ENTROPY:
  CAL/MOL-K            -13.3370
  CAL/GM-K              -0.8042
DENSITY:
  MOL/CC              1.6442-03
  GM/CC               2.7269-02
AVG MW                  16.5847

26
--

STREAM ID               26
FROM :                  HB-HXA-1
TO   :                  HB-CP-03

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              807.8182
  N2                   794.0931
  H2                   702.0008
  ARGON                 33.8856
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1.3758+04
  N2                  2.2245+04
  H2                  1415.1494
  ARGON               1353.6625
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             2337.7977
  KG/HR               3.8772+04
  L/MIN               2.9475+04
STATE VARIABLES:
  TEMP   C              90.0000
  PRES   BAR            39.2553
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -3380.8224
  CAL/GM              -203.8516
  CAL/SEC            -2.1955+06
ENTROPY:
  CAL/MOL-K            -11.8379
```

```
  CAL/GM-K              -0.7138
DENSITY:
  MOL/CC              1.3219-03
  GM/CC               2.1924-02
AVG MW                  16.5847

27
--

STREAM ID               27
FROM :                  HB-CP-03
TO   :                  HB-HXA-2

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              807.8182
  N2                   794.0931
  H2                   702.0008
  ARGON                 33.8856
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1.3758+04
  N2                  2.2245+04
  H2                  1415.1494
  ARGON               1353.6625
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             2337.7977
  KG/HR               3.8772+04
  L/MIN               1.8737+04
STATE VARIABLES:
  TEMP   C             192.5954
  PRES   BAR            81.0600
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -2587.0749
  CAL/GM              -155.9915
  CAL/SEC            -1.6800+06
ENTROPY:
  CAL/MOL-K            -11.3468
  CAL/GM-K              -0.6842
DENSITY:
  MOL/CC              2.0795-03
  GM/CC               3.4488-02
AVG MW                  16.5847

28
--

STREAM ID               28
FROM :                  HB-HXA-2
```

```
TO   :                  HB-RXN


CONV. MAX. REL. ERR:  6.5813-02
SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              807.8182
  N2                   794.0931
  H2                   702.0008
  ARGON                 33.8856
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1.3758+04
  N2                  2.2245+04
  H2                  1415.1494
  ARGON               1353.6625
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             2337.7977
  KG/HR               3.8772+04
  L/MIN               2.0227+04
STATE VARIABLES:
  TEMP   C             225.0000
  PRES   BAR            80.7153
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -2311.4996
  CAL/GM              -139.3753
  CAL/SEC            -1.5011+06
ENTROPY:
  CAL/MOL-K            -10.7663
  CAL/GM-K              -0.6492
DENSITY:
  MOL/CC              1.9263-03
  GM/CC               3.1947-02
AVG MW                  16.5847

29
--

STREAM ID               29
FROM :                  HB-RXN
TO   :                  HB-HXA-2

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              873.5322
  N2                   698.2629
  H2                   561.5493
  ARGON                 32.7816
```

```
  WATER                   0.0
COMPONENTS: KG/HR
  AMMONIA              1.4877+04
  N2                   1.9561+04
  H2                   1132.0160
  ARGON                1309.5581
  WATER                   0.0
TOTAL FLOW:
  KMOL/HR              2166.1259
  KG/HR                3.6879+04
  L/MIN                2.5421+04
STATE VARIABLES:
  TEMP   C              400.0000
  PRES   BAR             81.0600
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  CAL/MOL             -1386.1469
  CAL/GM                -81.4166
  CAL/SEC             -8.3405+05
ENTROPY:
  CAL/MOL-K              -9.4569
  CAL/GM-K               -0.5555
DENSITY:
  MOL/CC               1.4202-03
  GM/CC                2.4179-02
AVG MW                   17.0254

30
--

STREAM ID                30
FROM :                   HB-HXA-2
TO   :                   HB-HXA-3

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: KMOL/HR
  AMMONIA               873.5322
  N2                    698.2629
  H2                    561.5493
  ARGON                  32.7816
  WATER                   0.0
COMPONENTS: KG/HR
  AMMONIA              1.4877+04
  N2                   1.9561+04
  H2                   1132.0160
  ARGON                1309.5581
  WATER                   0.0
TOTAL FLOW:
  KMOL/HR              2166.1259
  KG/HR                3.6879+04
  L/MIN                2.4149+04
```

```
STATE VARIABLES:
  TEMP   C             367.0686
  PRES   BAR            81.0600
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -1683.5624
  CAL/GM               -98.8855
  CAL/SEC            -1.0130+06
ENTROPY:
  CAL/MOL-K             -9.9099
  CAL/GM-K              -0.5821
DENSITY:
  MOL/CC              1.4950-03
  GM/CC               2.5453-02
AVG MW                  17.0254

31
--

STREAM ID               31
FROM :                  HB-HXA-3
TO   :                  HB-HXA-1


CONV. MAX. REL. ERR: -5.2808-02
SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              873.5322
  N2                   698.2629
  H2                   561.5493
  ARGON                 32.7816
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1.4877+04
  N2                  1.9561+04
  H2                  1132.0160
  ARGON               1309.5581
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             2166.1259
  KG/HR               3.6879+04
  L/MIN               2.4162+04
STATE VARIABLES:
  TEMP   C             364.8045
  PRES   BAR            80.7153
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -1703.7667
  CAL/GM              -100.0722
```

```
  CAL/SEC            -1.0252+06
ENTROPY:
  CAL/MOL-K             -9.9329
  CAL/GM-K              -0.5834
DENSITY:
  MOL/CC              1.4942-03
  GM/CC               2.5439-02
AVG MW                  17.0254

32
--

STREAM ID               32
FROM :                  HB-HXA-1
TO   :                  HB-HXA-4

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA              895.4369
  N2                   737.1927
  H2                   561.5867
  ARGON                 33.2336
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1.5250+04
  N2                  2.0651+04
  H2                  1132.0913
  ARGON               1327.6169
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             2227.4499
  KG/HR               3.8361+04
  L/MIN               5.0674+04
STATE VARIABLES:
  TEMP   C             305.5963
  PRES   BAR            35.4637
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -2187.2785
  CAL/GM              -127.0059
  CAL/SEC            -1.3533+06
ENTROPY:
  CAL/MOL-K             -9.0742
  CAL/GM-K              -0.5269
DENSITY:
  MOL/CC              7.3260-04
  GM/CC               1.2617-02
AVG MW                  17.2219

33
--
```

```
STREAM ID                33
FROM :                   HB-HXA-4
TO   :                   B4

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: KMOL/HR
  AMMONIA               895.4369
  N2                    737.1927
  H2                    561.5867
  ARGON                  33.2336
  WATER                   0.0
COMPONENTS: KG/HR
  AMMONIA              1.5250+04
  N2                   2.0651+04
  H2                   1132.0913
  ARGON                1327.6169
  WATER                   0.0
TOTAL FLOW:
  KMOL/HR              2227.4499
  KG/HR                3.8361+04
  L/MIN                4.8457+04
STATE VARIABLES:
  TEMP   C              275.6711
  PRES   BAR             35.1190
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  CAL/MOL             -2445.0335
  CAL/GM               -141.9727
  CAL/SEC             -1.5128+06
ENTROPY:
  CAL/MOL-K              -9.5120
  CAL/GM-K               -0.5523
DENSITY:
  MOL/CC               7.6612-04
  GM/CC                1.3194-02
AVG MW                   17.2219

34
--

STREAM ID                34
FROM :                   HB-S-01
TO   :                   HB-S-02

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: KMOL/HR
  AMMONIA                90.4449
  N2                      0.3370
  H2                      0.1454
```

```
  ARGON               3.9038-02
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1540.3279
  N2                     9.4413
  H2                     0.2932
  ARGON                  1.5595
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR               90.9664
  KG/HR               1551.6219
  L/MIN                 46.4395
STATE VARIABLES:
  TEMP   C              30.0000
  PRES   BAR            39.6000
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -1.5846+04
  CAL/GM             -929.0029
  CAL/SEC            -4.0041+05
ENTROPY:
  CAL/MOL-K            -44.5577
  CAL/GM-K              -2.6123
DENSITY:
  MOL/CC              3.2647-02
  GM/CC                  0.5569
AVG MW                  17.0571

35
--

STREAM ID               35
FROM :                  HB-S-02
TO   :                  HB-CP-02

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA                2.9649
  N2                     0.3166
  H2                     0.1413
  ARGON               3.2772-02
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA               50.4939
  N2                     8.8696
  H2                     0.2849
  ARGON                  1.3092
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR                3.4556
  KG/HR                 60.9575
```

```
  L/MIN                128.9968
STATE VARIABLES:
  TEMP   C              20.0000
  PRES   BAR            10.1325
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -9566.0182
  CAL/GM              -542.2868
  CAL/SEC            -9182.3445
ENTROPY:
  CAL/MOL-K            -24.2168
  CAL/GM-K              -1.3728
DENSITY:
  MOL/CC              4.4647-04
  GM/CC               7.8758-03
AVG MW                  17.6401

36
--

STREAM ID               36
FROM :                  HB-CP-02
TO   :                  B20

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA                2.9649
  N2                     0.3166
  H2                     0.1413
  ARGON               3.2772-02
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA               50.4939
  N2                     8.8696
  H2                     0.2849
  ARGON                  1.3092
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR                3.4556
  KG/HR                 60.9575
  L/MIN                 50.2032
STATE VARIABLES:
  TEMP   C             171.0260
  PRES   BAR            39.6000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -8357.6044
  CAL/GM              -473.7832
  CAL/SEC            -8022.3977
```

```
ENTROPY:
  CAL/MOL-K            -23.4255
  CAL/GM-K              -1.3280
DENSITY:
  MOL/CC              1.1472-03
  GM/CC               2.0237-02
AVG MW                  17.6401

37
--

STREAM ID               37
FROM :                  B20
TO   :                  B21

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA                2.9056
  N2                     0.3103
  H2                     0.1385
  ARGON               3.2116-02
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA               49.4840
  N2                     8.6922
  H2                     0.2792
  ARGON                  1.2830
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR                3.3865
  KG/HR                 59.7383
  L/MIN                 49.1991
STATE VARIABLES:
  TEMP   C             171.0259
  PRES   BAR            39.6000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -8357.6044
  CAL/GM              -473.7832
  CAL/SEC            -7861.9497
ENTROPY:
  CAL/MOL-K            -23.4255
  CAL/GM-K              -1.3280
DENSITY:
  MOL/CC              1.1472-03
  GM/CC               2.0237-02
AVG MW                  17.6401

38
--
```

```
STREAM ID                38
FROM :                   ----
TO   :                   HB-HXA-3

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: KMOL/HR
  AMMONIA                 0.0
  N2                      0.0
  H2                      0.0
  ARGON                   0.0
  WATER                  97.3618
COMPONENTS: KG/HR
  AMMONIA                 0.0
  N2                      0.0
  H2                      0.0
  ARGON                   0.0
  WATER                1754.0000
TOTAL FLOW:
  KMOL/HR                97.3618
  KG/HR                1754.0000
  L/MIN                  29.2341
STATE VARIABLES:
  TEMP   C                7.2222
  PRES   BAR              1.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  CAL/MOL             -6.8588+04
  CAL/GM              -3807.2336
  CAL/SEC             -1.8550+06
ENTROPY:
  CAL/MOL-K             -40.0894
  CAL/GM-K               -2.2253
DENSITY:
  MOL/CC               5.5507-02
  GM/CC                   1.0000
AVG MW                   18.0153

39
--

STREAM ID                39
FROM :                   ----
TO   :                   HB-HXA-4

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: KMOL/HR
  AMMONIA                 0.0
  N2                      0.0
  H2                      0.0
  ARGON                   0.0
```

```
  WATER                 1277.2491
COMPONENTS: KG/HR
  AMMONIA                  0.0
  N2                       0.0
  H2                       0.0
  ARGON                    0.0
  WATER                 2.3010+04
TOTAL FLOW:
  KMOL/HR               1277.2491
  KG/HR                 2.3010+04
  L/MIN                  383.5102
STATE VARIABLES:
  TEMP   C                 7.2222
  PRES   BAR               1.0000
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  CAL/MOL              -6.8588+04
  CAL/GM               -3807.2336
  CAL/SEC              -2.4335+07
ENTROPY:
  CAL/MOL-K              -40.0894
  CAL/GM-K                -2.2253
DENSITY:
  MOL/CC                5.5507-02
  GM/CC                    1.0000
AVG MW                    18.0153

40
--

STREAM ID                 40
FROM :                    HB-HXA-3
TO   :                    ----

SUBSTREAM: MIXED
PHASE:                    LIQUID
COMPONENTS: KMOL/HR
  AMMONIA                  0.0
  N2                       0.0
  H2                       0.0
  ARGON                    0.0
  WATER                   97.3618
COMPONENTS: KG/HR
  AMMONIA                  0.0
  N2                       0.0
  H2                       0.0
  ARGON                    0.0
  WATER                 1754.0000
TOTAL FLOW:
  KMOL/HR                 97.3618
  KG/HR                 1754.0000
  L/MIN                   29.3784
```

```
STATE VARIABLES:
  TEMP   C               32.2222
  PRES   BAR              1.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  CAL/MOL            -6.8139+04
  CAL/GM             -3782.2820
  CAL/SEC            -1.8428+06
ENTROPY:
  CAL/MOL-K            -38.5536
  CAL/GM-K              -2.1400
DENSITY:
  MOL/CC              5.5234-02
  GM/CC                   0.9951
AVG MW                  18.0153

41
--

STREAM ID               41
FROM :                  HB-HXA-4
TO   :                  ----

SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: KMOL/HR
  AMMONIA                 0.0
  N2                      0.0
  H2                      0.0
  ARGON                   0.0
  WATER               1277.2491
COMPONENTS: KG/HR
  AMMONIA                 0.0
  N2                      0.0
  H2                      0.0
  ARGON                   0.0
  WATER               2.3010+04
TOTAL FLOW:
  KMOL/HR             1277.2491
  KG/HR               2.3010+04
  L/MIN                385.4031
STATE VARIABLES:
  TEMP   C               32.2222
  PRES   BAR              1.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  CAL/MOL            -6.8139+04
  CAL/GM             -3782.2820
  CAL/SEC            -2.4175+07
ENTROPY:
```

```
  CAL/MOL-K             -38.5536
  CAL/GM-K               -2.1400
DENSITY:
  MOL/CC               5.5234-02
  GM/CC                   0.9951
AVG MW                   18.0153

INPUT
-----

STREAM ID                INPUT
FROM :                   ----
TO   :                   B21

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: KMOL/HR
  AMMONIA                 0.0
  N2                     57.0400
  H2                    140.4000
  ARGON                   0.6600
  WATER                   0.0
COMPONENTS: KG/HR
  AMMONIA                 0.0
  N2                   1597.8889
  H2                    283.0296
  ARGON                  26.3657
  WATER                   0.0
TOTAL FLOW:
  KMOL/HR               198.1000
  KG/HR                1907.2841
  L/MIN                2179.3562
STATE VARIABLES:
  TEMP   C               35.0000
  PRES   BAR             39.6000
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  CAL/MOL                69.2039
  CAL/GM                  7.1879
  CAL/SEC              3808.1389
ENTROPY:
  CAL/MOL-K              -5.8566
  CAL/GM-K               -0.6083
DENSITY:
  MOL/CC               1.5150-03
  GM/CC                1.4586-02
AVG MW                    9.6279

OUT
---

STREAM ID                OUT
```

```
FROM :                  HB-S-02
TO   :                  ----

SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: KMOL/HR
  AMMONIA               87.4800
  N2                  2.0409-02
  H2                  4.1079-03
  ARGON               6.2665-03
  WATER                  0.0
COMPONENTS: KG/HR
  AMMONIA             1489.8341
  N2                     0.5717
  H2                  8.2810-03
  ARGON                  0.2503
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR               87.5108
  KG/HR               1490.6644
  L/MIN                 43.3357
STATE VARIABLES:
  TEMP   C              20.0000
  PRES   BAR            10.1325
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -1.6164+04
  CAL/GM              -948.8955
  CAL/SEC            -3.9291+05
ENTROPY:
  CAL/MOL-K            -45.4736
  CAL/GM-K              -2.6696
DENSITY:
  MOL/CC              3.3656-02
  GM/CC                  0.5733
AVG MW                  17.0341

PURGE
-----

STREAM ID               PURGE
FROM :                  B20
TO   :                  ----

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: KMOL/HR
  AMMONIA             5.9298-02
  N2                  6.3324-03
  H2                  2.8265-03
  ARGON               6.5543-04
  WATER                  0.0
```

```
COMPONENTS: KG/HR
  AMMONIA                1.0099
  N2                     0.1774
  H2                  5.6979-03
  ARGON               2.6183-02
  WATER                  0.0
TOTAL FLOW:
  KMOL/HR             6.9112-02
  KG/HR                  1.2191
  L/MIN                  1.0041
STATE VARIABLES:
  TEMP   C             171.0259
  PRES   BAR            39.6000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  CAL/MOL            -8357.6044
  CAL/GM              -473.7832
  CAL/SEC             -160.4480
ENTROPY:
  CAL/MOL-K            -23.4255
  CAL/GM-K              -1.3280
DENSITY:
  MOL/CC              1.1472-03
  GM/CC               2.0237-02
AVG MW                  17.6401
```

C.1.1: Compressed Air

Safety Data Sheet

according to Regulation (EU) 2015/830

Compressed Air

Date of issue: 20/12/2010 Supersedes: 18/12/2015 Revision date: 10/07/2019 Version: 1.2

SDS reference: 2010492

Warning

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Trade name : Compressed Air, Alphahaz™Air, Smartop™Air, Purified Air, Medical Air

SDS no : 2010492

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

Relevant identified uses : Industrial and professional. Perform risk assessment prior to use.

Contact supplier for more information on uses.

Test gas/Calibration gas.

Purging.

Laboratory use.

Uses advised against : None.

1.3. Details of the supplier of the safety data sheet

Company identification :

AIR LIQUIDE SINGAPORE PTE LTD
HEAD OFFICE : 2 VENTURE DRIVE, VISION EXCHANGE, #22-28, SINGAPORE 608526
SPECIALGASES OFFICE, NO 24 JALAN BUROH SINGAPORE 619480
T +65 6 265 3788
https://industry.airliquide.sg/resources/safety-data-sheets-sds
Sg-info@airliquide.com

1.4. Emergency telephone number

Emergency telephone number : +65 6265 3788, +65 9619 9229 (After Office Hour)

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

Classification according to Regulation (EC) No. 1272/2008 [CLP]

Physical hazards Gases under pressure : Compressed gas H280

2.2. Label elements

Labelling according to Regulation (EC) No. 1272/2008 [CLP]

Hazard pictograms (CLP) :

GHS04

Signal word (CLP) : Warning

Hazard statements (CLP) : H280 - Contains gas under pressure; may explode if heated.

Precautionary statements (CLP)

- Storage : P403 - Store in a well-ventilated place.

2.3. Other hazards

: None.

SECTION 3: Composition/information on ingredients

3.1. Substances : Not applicable

3.2. Mixtures

Name	Product identifier	%	Classification according to Regulation (EC) No. 1272/2008 [CLP]
Nitrogen	(CAS-No.) 7727-37-9 (EC-No.) 231-783-9 (EC Index-No.) (REACH-no) *1	79	Press. Gas (Comp.), H280
Oxygen	(CAS-No.) 7782-44-7 (EC-No.) 231-956-9 (EC Index-No.) 008-001-00-8 (REACH-no) *1	21	Ox. Gas 1, H270 Press. Gas (Comp.), H280

Full text of H-statements: see section 16

Contains no other components or impurities which will influence the classification of the product.

**1: Listed in Annex IV / V REACH, exempted from registration.*

**2: Registration deadline not expired.*

**3: Registration not required: Substance manufactured or imported < 1t/y.*

SECTION 4: First aid measures

4.1. Description of first aid measures

- Inhalation : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
- Skin contact : Adverse effects not expected from this product.
- Eye contact : Adverse effects not expected from this product.
- Ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

: No effect on living tissue.
Refer to section 11.

4.3. Indication of any immediate medical attention and special treatment needed

: None.

SECTION 5: Firefighting measures

5.1. Extinguishing media

- Suitable extinguishing media	: Water spray or fog.
- Unsuitable extinguishing media	: Do not use water jet to extinguish.

5.2. Special hazards arising from the substance or mixture

Specific hazards	: Exposure to fire may cause containers to rupture/explode. Supports combustion.
Hazardous combustion products	: None.

5.3. Advice for firefighters

Specific methods	: Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas receptacles to rupture. Cool endangered receptacles with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems. If possible, stop flow of product. Use water spray or fog to knock down fire fumes if possible. Move containers away from the fire area if this can be done without risk. In confined space use self-contained breathing apparatus. Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask.
Special protective equipment for fire fighters	: Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters. Standard EN 469 - Protective clothing for firefighters. Standard - EN 659: Protective gloves for firefighters. Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask. In confined space use self-contained breathing apparatus.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

: Ensure adequate air ventilation.

Act in accordance with local emergency plan.

Stay upwind.

Try to stop release.

Evacuate area.

Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe.

Oxygen detectors should be used when asphyxiating gases may be released.

6.2. Environmental precautions

: Try to stop release.

None.

6.3. Methods and material for containment and cleaning up

: Ventilate area.

None.

6.4. Reference to other sections

: See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Safe use of the product	:	The product must be handled in accordance with good industrial hygiene and safety procedures. Only experienced and properly instructed persons should handle gases under pressure. Consider pressure relief device(s) in gas installations. Ensure the complete gas system was (or is regularily) checked for leaks before use. Do not smoke while handling product. Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Contact your gas supplier if in doubt. Use only oxygen approved lubricants and oxygen approved sealings. Avoid suck back of water, acid and alkalis. Do not breathe gas. Avoid release of product into work area.
Safe handling of the gas receptacle	:	Refer to supplier's container handling instructions. Do not allow backfeed into the container. Protect cylinders from physical damage; do not drag, roll, slide or drop. When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders. Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use. If user experiences any difficulty operating cylinder valve discontinue use and contact supplier. Never attempt to repair or modify container valves or safety relief devices. Damaged valves should be reported immediately to the supplier. Keep container valve outlets clean and free from contaminants particularly oil and water. Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment. Close container valve after each use and when empty, even if still connected to equipment. Never attempt to transfer gases from one cylinder/container to another. Never use direct flame or electrical heating devices to raise the pressure of a container. Do not remove or deface labels provided by the supplier for the identification of the cylinder contents. Suck back of water into the container must be prevented. Open valve slowly to avoid pressure shock.

7.2. Conditions for safe storage, including any incompatibilities

: Observe all regulations and local requirements regarding storage of containers.

Containers should not be stored in conditions likely to encourage corrosion.

Container valve guards or caps should be in place.

Containers should be stored in the vertical position and properly secured to prevent them from falling over.

Stored containers should be periodically checked for general condition and leakage.

Keep container below 50°C in a well ventilated place.

Store containers in location free from fire risk and away from sources of heat and ignition.

Keep away from combustible materials.

7.3. Specific end use(s)

: None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

OEL (Occupational Exposure Limits)	None available.
DNEL (Derived-No Effect Level)	None available.
PNEC (Predicted No-Effect Concentration)	None available.

8.2. Exposure controls

8.2.1. Appropriate engineering controls

: Systems under pressure should be regularily checked for leakages.
Consider the use of a work permit system e.g. for maintenance activities.
Provide adequate general and local exhaust ventilation.
Oxygen detectors should be used when asphyxiating gases may be released.

8.2.2. Individual protection measures, e.g. personal protective equipment

: A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered:
PPE compliant to the recommended EN/ISO standards should be selected.

• Eye/face protection	Wear safety glasses with side shields. Standard EN 166 - Personal eye-protection - specifications.
• Skin protection	
- Hand protection	Wear working gloves when handling gas containers. Standard EN 388 - Protective gloves against mechanical risk.
- Other	Wear safety shoes while handling containers. Standard EN ISO 20345 - Personal protective equipment - Safety footwear.
• Respiratory protection	Self contained breathing apparatus (SCBA) or positive pressure airline with mask are to be used in oxygen-deficient atmospheres. Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask. None necessary.
• Thermal hazards	None in addition to the above sections.

8.2.3. Environmental exposure controls

: Refer to local regulations for restriction of emissions to the atmosphere. See section 13 for specific methods for waste gas treatment.
None necessary.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Appearance

• Physical state at 20°C / 101.3kPa	Gas
• Colour	Mixture contains one or more component(s) which have the following colour(s): Colourless.
Odour	Odourless.
Odour threshold	Odour threshold is subjective and inadequate to warn of overexposure.
pH	Not applicable for gases and gas mixtures.
Melting point / Freezing point	Not known

Boiling point	: Not known
Flash point	: Not applicable for gases and gas mixtures.
Evaporation rate	: Not applicable for gases and gas mixtures.
Flammability (solid, gas)	: Non flammable.
Explosive limits	: Non flammable.
Vapour pressure [20°C]	: Not applicable.
Vapour pressure [50°C]	: Not applicable.
Vapour density	: Not applicable.
Relative density, gas (air=1)	: 1
Partition coefficient n-octanol/water (Log Kow)	: Not applicable for inorganic products.
Auto-ignition temperature	: Non flammable.
Decomposition temperature	: Not applicable.
Viscosity, kinematic	: No reliable data available.
Explosive properties	: Not applicable.
Oxidising properties	: Not applicable.

9.2. Other information

Molar mass	: 29 g/mol
Other data	: None.

SECTION 10: Stability and reactivity

10.1. Reactivity

: No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

: Stable under normal conditions.

10.3. Possibility of hazardous reactions

: None.

10.4. Conditions to avoid

: Avoid moisture in installation systems.

10.5. Incompatible materials

: For additional information on compatibility refer to ISO 11114.

None.

10.6. Hazardous decomposition products

: Under normal conditions of storage and use, hazardous decomposition products should not be produced.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity	: No toxicological effects from this product.
Skin corrosion/irritation	: No known effects from this product.
Serious eye damage/irritation	: No known effects from this product.
Respiratory or skin sensitisation	: No known effects from this product.
Germ cell mutagenicity	: No known effects from this product.
Carcinogenicity	: No known effects from this product.

Toxic for reproduction : Fertility	: No known effects from this product.
Toxic for reproduction : unborn child	: No known effects from this product.
STOT-single exposure	: No known effects from this product.
STOT-repeated exposure	: No known effects from this product.
Aspiration hazard	: Not applicable for gases and gas mixtures.

SECTION 12: Ecological information

12.1. Toxicity

Assessment	: No ecological damage caused by this product.
EC50 48h - Daphnia magna [mg/l]	: No data available.
EC50 72h - Algae [mg/l]	: No data available.
LC50 96 h - Fish [mg/l]	: No data available.

12.2. Persistence and degradability

Assessment	: No ecological damage caused by this product.

12.3. Bioaccumulative potential

Assessment	: No data available.

12.4. Mobility in soil

Assessment	: Because of its high volatility, the product is unlikely to cause ground or water pollution. Partition into soil is unlikely.

12.5. Results of PBT and vPvB assessment

Assessment	: No data available.

12.6. Other adverse effects

Other adverse effects	: No known effects from this product.
Effect on the ozone layer	: None.
Effect on global warming	: No known effects from this product.

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Contact supplier if guidance is required.

Do not discharge into any place where its accumulation could be dangerous.

Ensure that the emission levels from local regulations or operating permits are not exceeded.

Refer to the EIGA code of practice Doc.30 "Disposal of Gases", downloadable at http://www.eiga.eu for more guidance on suitable disposal methods.

Return unused product in original cylinder to supplier.

May be vented to atmosphere in a well ventilated place.

May be vented to atmosphere.

List of hazardous waste codes (from Commission Decision 2000/532/EC as amended)	: 16 05 05 : Gases in pressure containers other than those mentioned in 16 05 04.

13.2. Additional information

: External treatment and disposal of waste should comply with applicable local and/or national regulations.

SECTION 14: Transport information

14.1. UN number

UN-No.	: 1002

14.2. UN proper shipping name

Transport by road/rail (ADR/RID)	: AIR, COMPRESSED
Transport by air (ICAO-TI / IATA-DGR)	: Air, compressed
Transport by sea (IMDG)	: AIR, COMPRESSED

14.3. Transport hazard class(es)

Labelling :

2.2 : Non-flammable, non-toxic gases.

Transport by road/rail (ADR/RID)	
Class	: 2
Classification code	: 1A
Hazard identification number	: 20
Tunnel Restriction	: E - Passage forbidden through tunnels of category E
Transport by air (ICAO-TI / IATA-DGR)	
Class / Div. (Sub. risk(s))	: 2.2
Transport by sea (IMDG)	
Class / Div. (Sub. risk(s))	: 2.2
Emergency Schedule (EmS) - Fire	: F-C
Emergency Schedule (EmS) - Spillage	: S-V

14.4. Packing group

Transport by road/rail (ADR/RID)	: Not applicable
Transport by air (ICAO-TI / IATA-DGR)	: Not applicable
Transport by sea (IMDG)	: Not applicable

14.5. Environmental hazards

Transport by road/rail (ADR/RID)	: None.
Transport by air (ICAO-TI / IATA-DGR)	: None.
Transport by sea (IMDG)	: None.

14.6. Special precautions for user

Packing Instruction(s)

Transport by road/rail (ADR/RID)	: P200
Transport by air (ICAO-TI / IATA-DGR)	

Passenger and Cargo Aircraft : 200.

Cargo Aircraft only : 200.

Transport by sea (IMDG) : P200

Special transport precautions : Avoid transport on vehicles where the load space is not separated from the driver's compartment.

Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.

Before transporting product containers:

- Ensure there is adequate ventilation.
- Ensure that containers are firmly secured.
- Ensure cylinder valve is closed and not leaking.
- Ensure valve outlet cap nut or plug (where provided) is correctly fitted.
- Ensure valve protection device (where provided) is correctly fitted.

14.7. Transport in bulk according to Annex II of Marpol and the IBC Code

: Not applicable.

SECTION 15: Regulatory information

15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture

EU-Regulations

Restrictions on use : None.

Seveso Directive : 2012/18/EU (Seveso III) : Not covered.

National regulations

National legislation : Ensure all national/local regulations are observed.

15.2. Chemical safety assessment

: A CSA does not need to be carried out for this product.

SECTION 16: Other information

Indication of changes : Revised safety data sheet in accordance with commission regulation (EU) No 2015/830.

Abbreviations and acronyms	: ATE - Acute Toxicity Estimate CLP - Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008 REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006 EINECS - European Inventory of Existing Commercial Chemical Substances CAS# - Chemical Abstract Service number PPE - Personal Protection Equipment LC50 - Lethal Concentration to 50 % of a test population RMM - Risk Management Measures PBT - Persistent, Bioaccumulative and Toxic vPvB - Very Persistent and Very Bioaccumulative STOT- SE : Specific Target Organ Toxicity - Single Exposure CSA - Chemical Safety Assessment EN - European Standard UN - United Nations ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road IATA - International Air Transport Association IMDG code - International Maritime Dangerous Goods RID - Regulations concerning the International Carriage of Dangerous Goods by Rail WGK - Water Hazard Class STOT - RE : Specific Target Organ Toxicity - Repeated Exposure
Training advice	: The hazard of asphyxiation is often overlooked and must be stressed during operator training.
Further information	: Classification using data from databases maintained by the European Industrial Gases Association (EIGA). Classification in accordance with the calculation methods of Regulation (EC) 1272/2008 CLP.

Full text of H- and EUH-statements

Ox. Gas 1	Oxidising Gases, Category 1
Press. Gas (Comp.)	Gases under pressure : Compressed gas
H270	May cause or intensify fire; oxidiser.
H280	Contains gas under pressure; may explode if heated.

DISCLAIMER OF LIABILITY	: Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out. Details given in this document are believed to be correct at the time of going to press. Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

End of document

C.1.2: Hydrogen

Air Liquide	**SAFETY DATA SHEET**	Page : 1/11 Revised edition no : 1 Compilation date : 17 / 9 / 2018 Supersedes : 4 / 10 / 2017
	Hydrogen	**NOAL_0067A** Country : SE / Language : EN

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Trade name	: Hydrogen, Alphagaz 1 Hydrogen, Alphagaz 2 Hydrogen, Hydrogen N35, Hydrogen N50, Hydrogen N56
SDS no	: NOAL_0067A
Chemical description	: Hydrogen CAS-No. : 1333-74-0 EC-No. : 215-605-7 EC Index-No. : 001-001-00-9
Registration-No.	: Listed in Annex IV / V REACH, exempted from registration.
Chemical formula	: H_2

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

Relevant identified uses	: Industrial and professional. Perform risk assessment prior to use. Test gas/Calibration gas. Laboratory use. Chemical reaction / Synthesis. Use as a fuel. Shield gas for welding processes. Use for manufacture of electronic/photovoltaic components. Laser gas. Contact supplier for more information on uses.
Uses advised against	: Do not inflate in party balloons because of the risk of explosion. Consumer use.

1.3. Details of the supplier of the safety data sheet

Company identification

AIR LIQUIDE GAS AB
Lundavägen 151
21209 Malmö - SWEDEN
T +46 40 38 10 00
eunordic-sds@airliquide.com

E-Mail address (competent person)	: eunordic-sds@airliquide.com

1.4. Emergency telephone number

Emergency telephone number	: 112 Availability (24 / 7)

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

Classification according to Regulation (EC) No. 1272/2008 [CLP]

Physical hazards	Flammable gases, Category 1	H220
	Gases under pressure : Compressed gas	H280

2.2. Label elements

Labelling according to Regulation (EC) No. 1272/2008 [CLP]

Hazard pictograms (CLP) :

GHS02

GHS04

Signal word (CLP) : Danger

Hazard statements (CLP) : H220 - Extremely flammable gas..
H280 - Contains gas under pressure; may explode if heated..

Precautionary statements (CLP)

- Prevention : P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking..
- Response : P377 - Leaking gas fire: Do not extinguish, unless leak can be stopped safely..
  P381 - In case of leakage, eliminate all ignition sources.
- Storage : P403 - Store in a well-ventilated place..

2.3. Other hazards

: None.

SECTION 3: Composition/information on ingredients

3.1. Substances

Name	Product identifier	Composition [V-%]:	Classification according to Regulation (EC) No. 1272/2008 [CLP]
Hydrogen	(CAS-No.) 1333-74-0 (EC-No.) 215-605-7 (EC Index-No.) 001-001-00-9 (Registration-No.) *1	100	Flam. Gas 1, H220 Press. Gas (Comp.), H280

Contains no other components or impurities which will influence the classification of the product.

**1: Listed in Annex IV / V REACH, exempted from registration.*

**2: Registration deadline not expired.*

**3: Registration not required: Substance manufactured or imported < 1t/y.*

3.2. Mixtures

: Not established.

SECTION 4: First aid measures

4.1. Description of first aid measures

- Inhalation : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
- Skin contact : Adverse effects not expected from this product.
- Eye contact : Adverse effects not expected from this product.
- Ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

: Refer to section 11.

4.3. Indication of any immediate medical attention and special treatment needed

: None.

SECTION 5: Firefighting measures

5.1. Extinguishing media

- Suitable extinguishing media : Water spray or fog.
Dry powder.
- Unsuitable extinguishing media : Carbon dioxide.
Do not use water jet to extinguish.

5.2. Special hazards arising from the substance or mixture

Specific hazards : Exposure to fire may cause containers to rupture/explode.
Hazardous combustion products : None.

5.3. Advice for firefighters

Specific methods : Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas receptacles to rupture. Cool endangered receptacles with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems.

If possible, stop flow of product.

Use water spray or fog to knock down fire fumes if possible.

Do not extinguish a leaking gas flame unless absolutely necessary. Spontaneous/explosive re-ignition may occur. Extinguish any other fire.

Move containers away from the fire area if this can be done without risk.

Special protective equipment for fire fighters : In confined space use self-contained breathing apparatus.

Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters.

Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask.

Standard EN 469 - Protective clothing for firefighters. Standard - EN 659: Protective gloves for firefighters.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

: Try to stop release.

Evacuate area.

Monitor concentration of released product.

Consider the risk of potentially explosive atmospheres.

Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe.

Eliminate ignition sources.

Ensure adequate air ventilation.

Act in accordance with local emergency plan.

Stay upwind.

6.2. Environmental precautions

: Try to stop release.

6.3. Methods and material for containment and cleaning up

: Ventilate area.

6.4. Reference to other sections

: See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Safe use of the product : The product must be handled in accordance with good industrial hygiene and safety procedures.

Only experienced and properly instructed persons should handle gases under pressure.

Consider pressure relief device(s) in gas installations.

Ensure the complete gas system was (or is regularily) checked for leaks before use.

Do not smoke while handling product.

Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Contact your gas supplier if in doubt.

Avoid suck back of water, acid and alkalis.

Assess the risk of potentially explosive atmospheres and the need for explosion-proof equipment.

Purge air from system before introducing gas.

Take precautionary measures against static discharge.

Keep away from ignition sources (including static discharges).

Consider the use of only non-sparking tools.

Do not breathe gas.

Avoid release of product into atmosphere.

Ensure equipment is adequately earthed.

Safe handling of the gas receptacle : Refer to supplier's container handling instructions.

Do not allow backfeed into the container.

Protect cylinders from physical damage; do not drag, roll, slide or drop.

When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders.

Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use.

If user experiences any difficulty operating cylinder valve discontinue use and contact supplier.

Never attempt to repair or modify container valves or safety relief devices.

Damaged valves should be reported immediately to the supplier.

Keep container valve outlets clean and free from contaminants particularly oil and water.

Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment.

Close container valve after each use and when empty, even if still connected to equipment.

Never attempt to transfer gases from one cylinder/container to another.

Never use direct flame or electrical heating devices to raise the pressure of a container.

Do not remove or deface labels provided by the supplier for the identification of the cylinder contents.

Suck back of water into the container must be prevented.

Open valve slowly to avoid pressure shock.

7.2. Conditions for safe storage, including any incompatibilities

: Observe all regulations and local requirements regarding storage of containers.

Containers should not be stored in conditions likely to encourage corrosion.

Container valve guards or caps should be in place.

Containers should be stored in the vertical position and properly secured to prevent them from falling over.

Stored containers should be periodically checked for general condition and leakage.

Keep container below 50°C in a well ventilated place.

Store containers in location free from fire risk and away from sources of heat and ignition.

Keep away from combustible materials.

Segregate from oxidant gases and other oxidants in store.

All electrical equipment in the storage areas should be compatible with the risk of a potentially explosive atmosphere.

7.3. Specific end use(s)

: None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

OEL (Occupational Exposure Limits) : No data available.

DNEL (Derived-No Effect Level) : No data available.

PNEC (Predicted No-Effect Concentration) : No data available.

8.2. Exposure controls

8.2.1. Appropriate engineering controls

: Provide adequate general and local exhaust ventilation.

Product to be handled in a closed system.

Systems under pressure should be regularly checked for leakages.

Gas detectors should be used when flammable gases/vapours may be released.

Consider the use of a work permit system e.g. for maintenance activities.

8.2.2. Individual protection measures, e.g. personal protective equipment

: A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered:
PPE compliant to the recommended EN/ISO standards should be selected.

• Eye/face protection	: Wear safety glasses with side shields. Standard EN 166 - Personal eye-protection - specifications.
• Skin protection	
- Hand protection	: Wear working gloves when handling gas containers. Standard EN 388 - Protective gloves against mechanical risk.
- Other	: Consider the use of flame resistant anti-static safety clothing. Standard EN ISO 14116 - Limited flame spread materials. Standard EN ISO 1149-5 - Protective clothing: Electrostatic properties. Wear safety shoes while handling containers. Standard EN ISO 20345 - Personal protective equipment - Safety footwear.
• Respiratory protection	: None necessary.
• Thermal hazards	: None in addition to the above sections.

8.2.3. Environmental exposure controls

: Refer to local regulations for restriction of emissions to the atmosphere. See section 13 for specific methods for waste gas treatment.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Appearance

• Physical state at 20°C / 101.3kPa	: Gas.
• Colour	: Colourless.
Odour	: Odourless.
Odour threshold	: Odour threshold is subjective and inadequate to warn of overexposure.
pH value	: Not applicable for gases and gas mixtures.
Molar mass	: 2 g/mol
Melting point	: -259 °C
Boiling point	: -253 °C
Flash point	: Not applicable for gases and gas mixtures.
Critical temperature [°C]	: -240 °C
Evaporation rate (ether=1)	: Not applicable for gases and gas mixtures.
Flammability range	: 4 - 77 vol %
Vapour pressure [20°C]	: Not applicable.
Vapour pressure [50°C]	: Not applicable.
Relative density, gas (air=1)	: 0.07
Relative density, liquid (water=1)	: 0.07
Solubility in water	: 1.6 mg/l
Partition coefficient n-octanol/water [log Kow]	: Not applicable for inorganic gases.
Auto-ignition temperature	: 560 °C
Decomposition point [°C]	: Not applicable.
Viscosity [20°C]	: No reliable data available.
Explosive Properties	: Not applicable.
Oxidising Properties	: Not applicable.

9.2. Other information

Other data : Burns with an invisible flame.

SECTION 10: Stability and reactivity

10.1. Reactivity

: No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

: Stable under normal conditions.

10.3. Possibility of hazardous reactions

: Can form explosive mixture with air.
May react violently with oxidants.

10.4. Conditions to avoid

: Keep away from heat/sparks/open flames/hot surfaces. – No smoking.
Avoid moisture in installation systems.

10.5. Incompatible materials

: Air, Oxidisers.
For additional information on compatibility refer to ISO 11114.

10.6. Hazardous decomposition products

: Under normal conditions of storage and use, hazardous decomposition products should not be produced.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity	: No known toxicological effects from this product.
Skin corrosion/irritation	: No known effects from this product.
Serious eye damage/irritation	: No known effects from this product.
Respiratory or skin sensitisation	: No known effects from this product.
Germ cell mutagenicity	: No known effects from this product.
Carcinogenicity	: No known effects from this product.
Reproductive toxicity	: No known effects from this product. No known effects from this product.
STOT-single exposure	: No known effects from this product.
STOT-repeated exposure	: No known effects from this product.
Aspiration hazard	: Not applicable for gases and gas mixtures.

SECTION 12: Ecological information

12.1. Toxicity

Assessment	: No ecological damage caused by this product.
EC50 48h - Daphnia magna [mg/l]	: No data available.
EC50 72h - Algae [mg/l]	: No data available.
LC50 96 h - Fish [mg/l]	: No data available.

12.2. Persistence and degradability

Assessment : No ecological damage caused by this product.

12.3. Bioaccumulative potential

Assessment : No data available.

12.4. Mobility in soil

Assessment : Because of its high volatility, the product is unlikely to cause ground or water pollution.
Partition into soil is unlikely.

12.5. Results of PBT and vPvB assessment

Assessment : No data available.

12.6. Other adverse effects

Other adverse effects : No known effects from this product.
Effect on the ozone layer : None.
Global warming potential [CO2=1] : 6
Effect on global warming : Contains greenhouse gas(es).
When discharged in large quantities may contribute to the greenhouse effect.

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Contact supplier if guidance is required.

Do not discharge into areas where there is a risk of forming an explosive mixture with air. Waste gas should be flared through a suitable burner with flash back arrestor.

Do not discharge into any place where its accumulation could be dangerous.

Ensure that the emission levels from local regulations or operating permits are not exceeded.

Refer to the EIGA code of practice Doc.30 "Disposal of Gases", downloadable at http://www.eiga.org for more guidance on suitable disposal methods.

Return unused product in original cylinder to supplier.

List of hazardous waste codes (from Commission Decision 2001/118/EC) : 16 05 04 *: Gases in pressure containers (including halons) containing dangerous substances.

13.2. Additional information

: External treatment and disposal of waste should comply with applicable local and/or national regulations.

SECTION 14: Transport information

14.1. UN number

UN-No. : 1049

14.2. UN proper shipping name

Transport by road/rail (ADR/RID) : HYDROGEN, COMPRESSED
Transport by air (ICAO-TI / IATA-DGR) : Hydrogen, compressed
Transport by sea (IMDG) : HYDROGEN, COMPRESSED

14.3. Transport hazard class(es)

Labelling :

2.1 : Flammable gases.

Transport by road/rail (ADR/RID)

Class : 2.

Classification code : 1F.

Hazard identification number : 23.

Tunnel Restriction : B/D - Tank carriage : Passage forbidden through tunnels of category B, C, D and E. Other carriage : Passage forbidden through tunnels of category D and E.

Transport by air (ICAO-TI / IATA-DGR)

Class / Div. (Sub. risk(s)) : 2.1

Transport by sea (IMDG)

Class / Div. (Sub. risk(s)) : 2.1

Emergency Schedule (EmS) - Fire : F-D.

Emergency Schedule (EmS) - Spillage : S-U.

14.4. Packing group

Transport by road/rail (ADR/RID) : Not established.

Transport by air (ICAO-TI / IATA-DGR) : Not established.

Transport by sea (IMDG) : Not established.

14.5. Environmental hazards

Transport by road/rail (ADR/RID) : None.

Transport by air (ICAO-TI / IATA-DGR) : None.

Transport by sea (IMDG) : None.

14.6. Special precautions for user

Packing Instruction(s)

Transport by road/rail (ADR/RID) : P200.

Transport by air (ICAO-TI / IATA-DGR)

- Passenger and Cargo Aircraft : Forbidden.
- Cargo Aircraft only : 200.

Transport by sea (IMDG) : P200.

Special transport precautions : Avoid transport on vehicles where the load space is not separated from the driver's compartment.

Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.

Before transporting product containers:

- Ensure there is adequate ventilation.
- Ensure that containers are firmly secured.
- Ensure cylinder valve is closed and not leaking.

- Ensure valve outlet cap nut or plug (where provided) is correctly fitted.
- Ensure valve protection device (where provided) is correctly fitted.

14.7. Transport in bulk according to Annex II of Marpol and the IBC Code

: Not applicable.

SECTION 15: Regulatory information

15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture

EU-Regulations

Restrictions on use : None.
Seveso Directive : 2012/18/EU (Seveso III) : Listed.

National regulations

National legislation : Ensure all national/local regulations are observed.

15.2. Chemical safety assessment

A CSA does not need to be carried out for this product.

SECTION 16: Other information

Indication of changes : Revised safety data sheet in accordance with commission regulation (EU) No 453/2010.

Abbreviations and acronyms : ATE - Acute Toxicity Estimate
CLP - Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008
REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006
EINECS - European Inventory of Existing Commercial Chemical Substances
CAS# - Chemical Abstract Service number
PPE - Personal Protection Equipment
LC50 - Lethal Concentration to 50 % of a test population
RMM - Risk Management Measures
PBT - Persistent, Bioaccumulative and Toxic
vPvB - Very Persistent and Very Bioaccumulative
STOT- SE : Specific Target Organ Toxicity - Single Exposure
CSA - Chemical Safety Assessment
EN - European Standard
UN - United Nations
ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road
IATA - International Air Transport Association
IMDG code - International Maritime Dangerous Goods
RID - Regulations concerning the International Carriage of Dangerous Goods by Rail
WGK - Water Hazard Class

Training advice : Ensure operators understand the flammability hazard.

Full text of H- and EUH-statements

Flam. Gas 1	Flammable gases, Category 1
Press. Gas (Comp.)	Gases under pressure : Compressed gas
H220	Extremely flammable gas.
H280	Contains gas under pressure; may explode if heated.

DISCLAIMER OF LIABILITY : Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out.

Details given in this document are believed to be correct at the time of going to press.

Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

C.1.3: Nitrogen

Air Liquide	SAFETY DATA SHEET	Page : 1/10 Revised edition no : 1 Compilation date : 16 / 7 / 2018 Supersedes : 5 / 10 / 2017
	Nitrogen	**NOAL_0089A** Country : DK / Language : EN

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Trade name : Nitrogen, Nitrogen compressed, Nitrogen N48, Nitrogen N52, Nitrogen HG, Lasal 1, Lasal 2001, Aligal 1, Alphagaz N2 1, Alphagaz N2 2, Alphagaz 1 Nitrogen, Alphagaz 2 Nitrogen, Lasal 1, Phargalis 1, Albee Cool N2

SDS no : NOAL_0089A

Chemical description : Nitrogen
CAS-No. : 7727-37-9
EC-No. : 231-783-9
EC Index-No. : ---

Registration-No. : Listed in Annex IV / V REACH, exempted from registration.

Chemical formula : N_2

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

Relevant identified uses : Industrial and professional. Perform risk assessment prior to use.
Test gas/Calibration gas.
Laboratory use.
Purge gas, diluting gas, inerting gas.
Shield gas for welding processes.
Use for manufacture of electronic/photovoltaic components.
Contact supplier for more information on uses.

Uses advised against : Consumer use.

1.3. Details of the supplier of the safety data sheet

Company identification

AIR LIQUIDE Denmark A/S
Høje Taastrupvej 42
2630 Taastrup - DENMARK
T +45 76 25 25 25
eunordic-sds@airliquide.com

E-Mail address (competent person) : eunordic-sds@airliquide.com

1.4. Emergency telephone number

Emergency telephone number : 112
Availability
(24 / 7)

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

Classification according to Regulation (EC) No. 1272/2008 [CLP]

Physical hazards	Gases under pressure : Compressed gas	H280

2.2. Label elements

Labelling according to Regulation (EC) No. 1272/2008 [CLP]

Hazard pictograms (CLP) :

GHS04

Signal word (CLP) : Warning

Hazard statements (CLP) : H280 - Contains gas under pressure; may explode if heated..

Precautionary statements (CLP)

- Storage : P403 - Store in a well-ventilated place..

2.3. Other hazards

: Asphyxiant in high concentrations.

SECTION 3: Composition/information on ingredients

3.1. Substances

Name	Product identifier	Composition [V-%]:	Classification according to Regulation (EC) No. 1272/2008 [CLP]
Nitrogen	(CAS-No.) 7727-37-9 (EC-No.) 231-783-9 (EC Index-No.) --- (Registration-No.) *1	100	Press. Gas (Comp.), H280

Contains no other components or impurities which will influence the classification of the product.

**1: Listed in Annex IV / V REACH, exempted from registration.*

**2: Registration deadline not expired.*

**3: Registration not required: Substance manufactured or imported < 1t/y.*

3.2. Mixtures

: Not established.

SECTION 4: First aid measures

4.1. Description of first aid measures

- Inhalation : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
- Skin contact : Adverse effects not expected from this product.
- Eye contact : Adverse effects not expected from this product.
- Ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

: In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciousness. Victim may not be aware of asphyxiation.

Refer to section 11.

4.3. Indication of any immediate medical attention and special treatment needed

: None.

SECTION 5: Firefighting measures

5.1. Extinguishing media

- Suitable extinguishing media : Water spray or fog.
- Unsuitable extinguishing media : Do not use water jet to extinguish.

5.2. Special hazards arising from the substance or mixture

Specific hazards : Exposure to fire may cause containers to rupture/explode.
Hazardous combustion products : None.

5.3. Advice for firefighters

Specific methods : Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas receptacles to rupture. Cool endangered receptacles with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems.

If possible, stop flow of product.

Use water spray or fog to knock down fire fumes if possible.

Move containers away from the fire area if this can be done without risk.

Special protective equipment for fire fighters : In confined space use self-contained breathing apparatus.

Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters.

Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask.

Standard EN 469 - Protective clothing for firefighters. Standard - EN 659: Protective gloves for firefighters.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

: Try to stop release.

Evacuate area.

Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe.

Ensure adequate air ventilation.

Act in accordance with local emergency plan.

Stay upwind.

Oxygen detectors should be used when asphyxiating gases may be released.

6.2. Environmental precautions

: Try to stop release.

6.3. Methods and material for containment and cleaning up

: Ventilate area.

6.4. Reference to other sections

: See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Safe use of the product	: The product must be handled in accordance with good industrial hygiene and safety procedures. Only experienced and properly instructed persons should handle gases under pressure. Consider pressure relief device(s) in gas installations. Ensure the complete gas system was (or is regularily) checked for leaks before use. Do not smoke while handling product. Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Contact your gas supplier if in doubt. Avoid suck back of water, acid and alkalis. Do not breathe gas. Avoid release of product into atmosphere.
Safe handling of the gas receptacle	: Refer to supplier's container handling instructions. Do not allow backfeed into the container. Protect cylinders from physical damage; do not drag, roll, slide or drop. When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders. Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use. If user experiences any difficulty operating cylinder valve discontinue use and contact supplier. Never attempt to repair or modify container valves or safety relief devices. Damaged valves should be reported immediately to the supplier. Keep container valve outlets clean and free from contaminants particularly oil and water. Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment. Close container valve after each use and when empty, even if still connected to equipment. Never attempt to transfer gases from one cylinder/container to another. Never use direct flame or electrical heating devices to raise the pressure of a container. Do not remove or deface labels provided by the supplier for the identification of the cylinder contents. Suck back of water into the container must be prevented. Open valve slowly to avoid pressure shock.

7.2. Conditions for safe storage, including any incompatibilities

: Observe all regulations and local requirements regarding storage of containers.

Containers should not be stored in conditions likely to encourage corrosion.

Container valve guards or caps should be in place.

Containers should be stored in the vertical position and properly secured to prevent them from falling over.

Stored containers should be periodically checked for general condition and leakage.
Keep container below 50°C in a well ventilated place.
Store containers in location free from fire risk and away from sources of heat and ignition.
Keep away from combustible materials.

7.3. Specific end use(s)

: None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

OEL (Occupational Exposure Limits) : No data available.

DNEL (Derived-No Effect Level) : No data available.

PNEC (Predicted No-Effect Concentration) : No data available.

8.2. Exposure controls

8.2.1. Appropriate engineering controls

: Provide adequate general and local exhaust ventilation.
Systems under pressure should be regularily checked for leakages.
Oxygen detectors should be used when asphyxiating gases may be released.
Consider the use of a work permit system e.g. for maintenance activities.

8.2.2. Individual protection measures, e.g. personal protective equipment

: A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered:
PPE compliant to the recommended EN/ISO standards should be selected.

- Eye/face protection : Wear safety glasses with side shields.
  Standard EN 166 - Personal eye-protection - specifications.
- Skin protection
  - Hand protection : Wear working gloves when handling gas containers.
    Standard EN 388 - Protective gloves against mechanical risk.
  - Other : Wear safety shoes while handling containers.
    Standard EN ISO 20345 - Personal protective equipment - Safety footwear.
- Respiratory protection : Self contained breathing apparatus (SCBA) or positive pressure airline with mask are to be used in oxygen-deficient atmospheres.
  Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask.
- Thermal hazards : None in addition to the above sections.

8.2.3. Environmental exposure controls

: None necessary.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Appearance

• Physical state at 20°C / 101.3kPa	:	Gas.
• Colour	:	Colourless.
Odour	:	No odour warning properties.
Odour threshold	:	Odour threshold is subjective and inadequate to warn of overexposure.
pH value	:	Not applicable for gases and gas mixtures.
Molar mass	:	28 g/mol
Melting point	:	-210 °C
Boiling point	:	-196 °C
Flash point	:	Not applicable for gases and gas mixtures.
Critical temperature [°C]	:	-147 °C
Evaporation rate (ether=1)	:	Not applicable for gases and gas mixtures.
Flammability range	:	Non flammable.
Vapour pressure [20°C]	:	Not applicable.
Vapour pressure [50°C]	:	Not applicable.
Relative density, gas (air=1)	:	0.97
Relative density, liquid (water=1)	:	Not applicable.
Solubility in water	:	20 mg/l
Partition coefficient n-octanol/water [log Kow]	:	Not applicable for inorganic gases.
Auto-ignition temperature	:	Non flammable.
Decomposition point [°C]	:	Not applicable.
Viscosity [20°C]	:	No reliable data available.
Explosive Properties	:	Not applicable.
Oxidising Properties	:	Not applicable.

9.2. Other information

Other data : No additional information available

SECTION 10: Stability and reactivity

10.1. Reactivity

: No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

: Stable under normal conditions.

10.3. Possibility of hazardous reactions

: None.

10.4. Conditions to avoid

: Avoid moisture in installation systems.

10.5. Incompatible materials

: None.
For additional information on compatibility refer to ISO 11114.

10.6. Hazardous decomposition products

: None.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity : No known toxicological effects from this product.

Skin corrosion/irritation : No known effects from this product.

Serious eye damage/irritation : No known effects from this product.

Respiratory or skin sensitisation : No known effects from this product.

Germ cell mutagenicity : No known effects from this product.

Carcinogenicity : No known effects from this product.

Reproductive toxicity : No known effects from this product.
No known effects from this product.

STOT-single exposure : No known effects from this product.

STOT-repeated exposure : No known effects from this product.

Aspiration hazard : Not applicable for gases and gas mixtures.

SECTION 12: Ecological information

12.1. Toxicity

Assessment : No ecological damage caused by this product.

EC50 48h - Daphnia magna [mg/l] : No data available.

EC50 72h - Algae [mg/l] : No data available.

LC50 96 h - Fish [mg/l] : No data available.

12.2. Persistence and degradability

Assessment : No ecological damage caused by this product.

12.3. Bioaccumulative potential

Assessment : No data available.

12.4. Mobility in soil

Assessment : Because of its high volatility, the product is unlikely to cause ground or water pollution.
Partition into soil is unlikely.

12.5. Results of PBT and vPvB assessment

Assessment : No data available.

12.6. Other adverse effects

Other adverse effects : No known effects from this product.

Effect on the ozone layer : None.

Effect on global warming : None.

SECTION 13: Disposal considerations

13.1. Waste treatment methods

May be vented to atmosphere in a well ventilated place.
Do not discharge into any place where its accumulation could be dangerous.

Return unused product in original cylinder to supplier.

List of hazardous waste codes (from Commission Decision 2001/118/EC) : 16 05 05 : Gases in pressure containers other than those mentioned in 16 05 04.

13.2. Additional information

: External treatment and disposal of waste should comply with applicable local and/or national regulations.

SECTION 14: Transport information

14.1. UN number

UN-No. : 1066

14.2. UN proper shipping name

Transport by road/rail (ADR/RID) : NITROGEN, COMPRESSED
Transport by air (ICAO-TI / IATA-DGR) : Nitrogen, compressed
Transport by sea (IMDG) : NITROGEN, COMPRESSED

14.3. Transport hazard class(es)

Labelling :

2.2 : Non-flammable, non-toxic gases.

Transport by road/rail (ADR/RID)
Class : 2.
Classification code : 1A.
Hazard identification number : 20.
Tunnel Restriction : E - Passage forbidden through tunnels of category E.
Transport by air (ICAO-TI / IATA-DGR)
Class / Div. (Sub. risk(s)) : 2.2
Transport by sea (IMDG)
Class / Div. (Sub. risk(s)) : 2.2
Emergency Schedule (EmS) - Fire : F-C.
Emergency Schedule (EmS) - Spillage : S-V.

14.4. Packing group

Transport by road/rail (ADR/RID) : Not established.
Transport by air (ICAO-TI / IATA-DGR) : Not established.
Transport by sea (IMDG) : Not established.

14.5. Environmental hazards

Transport by road/rail (ADR/RID) : None.

Transport by air (ICAO-TI / IATA-DGR) : None.

Transport by sea (IMDG) : None.

14.6. Special precautions for user

Packing Instruction(s)

Transport by road/rail (ADR/RID) : P200.

Transport by air (ICAO-TI / IATA-DGR)

  Passenger and Cargo Aircraft : 200.

  Cargo Aircraft only : 200.

Transport by sea (IMDG) : P200.

Special transport precautions : Avoid transport on vehicles where the load space is not separated from the driver's compartment.

Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.

Before transporting product containers:

- Ensure there is adequate ventilation.
- Ensure that containers are firmly secured.
- Ensure cylinder valve is closed and not leaking.
- Ensure valve outlet cap nut or plug (where provided) is correctly fitted.
- Ensure valve protection device (where provided) is correctly fitted.

14.7. Transport in bulk according to Annex II of Marpol and the IBC Code

: Not applicable.

SECTION 15: Regulatory information

15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture

EU-Regulations

Restrictions on use : None.

Seveso Directive : 2012/18/EU (Seveso III) : Not covered.

National regulations

National legislation : Ensure all national/local regulations are observed.

15.2. Chemical safety assessment

A CSA does not need to be carried out for this product.

SECTION 16: Other information

Indication of changes : Revised safety data sheet in accordance with commission regulation (EU) No 453/2010.

Abbreviations and acronyms : ATE - Acute Toxicity Estimate

CLP - Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008

REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006

EINECS - European Inventory of Existing Commercial Chemical Substances

CAS# - Chemical Abstract Service number

PPE - Personal Protection Equipment

LC50 - Lethal Concentration to 50 % of a test population

RMM - Risk Management Measures

PBT - Persistent, Bioaccumulative and Toxic

vPvB - Very Persistent and Very Bioaccumulative

STOT- SE : Specific Target Organ Toxicity - Single Exposure

CSA - Chemical Safety Assessment

EN - European Standard

UN - United Nations

ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road

IATA - International Air Transport Association

IMDG code - International Maritime Dangerous Goods

RID - Regulations concerning the International Carriage of Dangerous Goods by Rail

WGK - Water Hazard Class

Training advice : The hazard of asphyxiation is often overlooked and must be stressed during operator training.

Full text of H- and EUH-statements

Press. Gas (Comp.)	Gases under pressure : Compressed gas
H280	Contains gas under pressure; may explode if heated.

DISCLAIMER OF LIABILITY : Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out.

Details given in this document are believed to be correct at the time of going to press.

Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

C.1.4: Oxygen

Safety Data Sheet

according to Regulation (EU) 2015/830

Oxygen

Date of issue: 28/12/2010 Supersedes: 17/12/2015 Revision date: 10/07/2019 Version: 1.2

SDS reference: 2010479

Danger

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Trade name : Oxygen, Alphahaz™ Oxygen, Purified/ Compressed Oxygen, Medical Oxygen, PRESENCE™, TAKEO™, Breathing Oxygen.

SDS no : 2010479

Chemical description : Oxygen
CAS-No. : 7782-44-7
EC-No. : 231-956-9
EC Index-No. : 008-001-00-8

Registration-No. : Listed in Annex IV / V REACH, exempted from registration.

Chemical formula : O2

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

Relevant identified uses : Industrial and professional. Perform risk assessment prior to use.
Test gas/Calibration gas.
Welding, cutting, heating and brazing.
Shield gas for welding processes.
Use for manufacture of electronic/photovoltaic components.
Water treatment.
Laser gas.
Laboratory use.
Food applications.
Contact supplier for more information on uses.

Uses advised against : Consumer use.

1.3. Details of the supplier of the safety data sheet

Company identification : AIR LIQUIDE SINGAPORE PTE LTD
HEAD OFFICE : 2 VENTURE DRIVE, VISION EXCHANGE, #22-28, SINGAPORE 608526
SPECIALGASES OFFICE, NO 24 JALAN BUROH SINGAPORE 619480
T +65 6 265 3788
https://industry.airliquide.sg/resources/safety-data-sheets-sds
Sg-info@airliquide.com

1.4. Emergency telephone number

Emergency telephone number : +65 6265 3788, +65 9619 9229 (After Office Hour)

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

Classification according to Regulation (EC) No. 1272/2008 [CLP]

Physical hazards	Oxidising Gases, Category 1	H270
	Gases under pressure : Compressed gas	H280

2.2. Label elements

Labelling according to Regulation (EC) No. 1272/2008 [CLP]

Hazard pictograms (CLP) :


GHS03


GHS04

Signal word (CLP) : Danger
Hazard statements (CLP) : H270 - May cause or intensify fire; oxidiser.
H280 - Contains gas under pressure; may explode if heated.

Precautionary statements (CLP)
- Prevention : P220 - Keep away from combustible materials.
P244 - Keep valves and fittings free from oil and grease.
- Response : P370+P376 - In case of fire: stop leak if safe to do so.
- Storage : P403 - Store in a well-ventilated place.

2.3. Other hazards

: None.

SECTION 3: Composition/information on ingredients

3.1. Substances

Name	Product identifier	%	Classification according to Regulation (EC) No. 1272/2008 [CLP]
Oxygen	(CAS-No.) 7782-44-7 (EC-No.) 231-956-9 (EC Index-No.) 008-001-00-8 (Registration-No.) *1	100	Ox. Gas 1, H270 Press. Gas (Comp.), H280

Contains no other components or impurities which will influence the classification of the product.

**1: Listed in Annex IV / V REACH, exempted from registration.*

**2: Registration deadline not expired.*

**3: Registration not required: Substance manufactured or imported < 1t/y.*

3.2. Mixtures

: Not applicable

SECTION 4: First aid measures

4.1. Description of first aid measures

- Inhalation	: Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Perform cardiopulmonary resuscitation if breathing stopped. Remove victim to uncontaminated area.
- Skin contact	: Adverse effects not expected from this product.
- Eye contact	: Adverse effects not expected from this product.
- Ingestion	: Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

: Continuous inhalation of concentrations higher than 75% may cause nausea, dizziness, respiratory difficulty and convulsion.

Refer to section 11.

4.3. Indication of any immediate medical attention and special treatment needed

: None.

SECTION 5: Firefighting measures

5.1. Extinguishing media

- Suitable extinguishing media	: Water spray or fog.
- Unsuitable extinguishing media	: Do not use water jet to extinguish.

5.2. Special hazards arising from the substance or mixture

Specific hazards	: Supports combustion. Exposure to fire may cause containers to rupture/explode.
Hazardous combustion products	: None.

5.3. Advice for firefighters

Specific methods	: Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas receptacles to rupture. Cool endangered receptacles with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems. If possible, stop flow of product. Use water spray or fog to knock down fire fumes if possible. Move containers away from the fire area if this can be done without risk.
Special protective equipment for fire fighters	: Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters. Standard EN 469 - Protective clothing for firefighters. Standard - EN 659: Protective gloves for firefighters.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

: Try to stop release.

Evacuate area.

Monitor concentration of released product.

Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe.

Eliminate ignition sources.

Ensure adequate air ventilation.

Act in accordance with local emergency plan.

Stay upwind.

6.2. Environmental precautions

: Try to stop release.

6.3. Methods and material for containment and cleaning up

: Ventilate area.

6.4. Reference to other sections

: See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Safe use of the product : Do not breathe gas.

The product must be handled in accordance with good industrial hygiene and safety procedures.

Only experienced and properly instructed persons should handle gases under pressure.

Consider pressure relief device(s) in gas installations.

Ensure the complete gas system was (or is regularily) checked for leaks before use.

Do not smoke while handling product.

Keep equipment free from oil and grease. For more guidance, refer to the EIGA Doc. 33 - Cleaning of Equipment for Oxygen Service downloadable at http://www.eiga.eu.

Use no oil or grease.

Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Contact your gas supplier if in doubt.

Use only oxygen approved lubricants and oxygen approved sealings.

Use only with equipment cleaned for oxygen service and rated for cylinder pressure.

Avoid suck back of water, acid and alkalis.

Safe handling of the gas receptacle : Refer to supplier's container handling instructions.

Do not allow backfeed into the container.

Protect cylinders from physical damage; do not drag, roll, slide or drop.

When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders.

Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use.

If user experiences any difficulty operating cylinder valve discontinue use and contact supplier.

Never attempt to repair or modify container valves or safety relief devices.

Damaged valves should be reported immediately to the supplier.

Keep container valve outlets clean and free from contaminants particularly oil and water.

Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment.

Close container valve after each use and when empty, even if still connected to equipment.

Never attempt to transfer gases from one cylinder/container to another.

Never use direct flame or electrical heating devices to raise the pressure of a container.

Do not remove or deface labels provided by the supplier for the identification of the cylinder contents.

Suck back of water into the container must be prevented.

Open valve slowly to avoid pressure shock.

7.2. Conditions for safe storage, including any incompatibilities

: Observe all regulations and local requirements regarding storage of containers.

Containers should not be stored in conditions likely to encourage corrosion.

Container valve guards or caps should be in place.

Containers should be stored in the vertical position and properly secured to prevent them from falling over.

Stored containers should be periodically checked for general condition and leakage.

Keep container below 50°C in a well ventilated place.

Segregate from flammable gases and other flammable materials in store.

Store containers in location free from fire risk and away from sources of heat and ignition.

Keep away from combustible materials.

7.3. Specific end use(s)

: None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

OEL (Occupational Exposure Limits)	: None available.
DNEL (Derived-No Effect Level)	: None available.
PNEC (Predicted No-Effect Concentration)	: None available.

8.2. Exposure controls

8.2.1. Appropriate engineering controls

: Provide adequate general and local exhaust ventilation.

Systems under pressure should be regularily checked for leakages.

Avoid oxygen rich (>23,5%) atmospheres.

Gas detectors should be used when oxidising gases may be released.

Consider the use of a work permit system e.g. for maintenance activities.

8.2.2. Individual protection measures, e.g. personal protective equipment

: A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered:
PPE compliant to the recommended EN/ISO standards should be selected.

• Eye/face protection	: Wear safety glasses with side shields. Standard EN 166 - Personal eye-protection - specifications.
• Skin protection	
- Hand protection	: Wear working gloves when handling gas containers. Standard EN 388 - Protective gloves against mechanical risk.
- Other	: Consider the use of flame resistant safety clothing. Standard EN ISO 14116 - Limited flame spread materials. Wear safety shoes while handling containers. Standard EN ISO 20345 - Personal protective equipment - Safety footwear.
• Respiratory protection	: None necessary.
• Thermal hazards	: None in addition to the above sections.

8.2.3. Environmental exposure controls

: Refer to local regulations for restriction of emissions to the atmosphere. See section 13 for specific methods for waste gas treatment.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Appearance		
• Physical state at 20°C / 101.3kPa	:	Gas
• Colour	:	Colourless.
Odour	:	No odour warning properties.
Odour threshold	:	Odour threshold is subjective and inadequate to warn of overexposure.
pH	:	Not applicable for gases and gas mixtures.
Melting point / Freezing point	:	-219 °C
Boiling point	:	-183 °C
Flash point	:	Not applicable for gases and gas mixtures.
Evaporation rate	:	Not applicable for gases and gas mixtures.
Flammability (solid, gas)	:	Non flammable.
Explosive limits	:	Non flammable.
Vapour pressure [20°C]	:	Not applicable.
Vapour pressure [50°C]	:	Not applicable.
Vapour density	:	Not applicable.
Relative density, liquid (water=1)	:	1.1
Relative density, gas (air=1)	:	1.1
Water solubility	:	39 mg/l
Partition coefficient n-octanol/water (Log Kow)	:	Not applicable for inorganic products.
Auto-ignition temperature	:	Non flammable.
Decomposition temperature	:	Not applicable.
Viscosity, kinematic	:	No reliable data available.
Explosive properties	:	Not applicable.
Oxidising properties	:	Oxidiser.

9.2. Other information

Molar mass	:	32 g/mol
Critical temperature [°C]	:	-118 °C
- Coefficient of oxygen equivalency (Ci)	:	1

SECTION 10: Stability and reactivity

10.1. Reactivity

: No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

: Stable under normal conditions.

10.3. Possibility of hazardous reactions

: Violently oxidises organic material.

10.4. Conditions to avoid

: Avoid moisture in installation systems.

10.5. Incompatible materials

: May react violently with combustible materials.

May react violently with reducing agents.

Keep equipment free from oil and grease. For more guidance, refer to the EIGA Doc. 33 - Cleaning of Equipment for Oxygen Service downloadable at http://www.eiga.eu.

Consider the potential toxicity hazard due to the presence of chlorinated or fluorinated polymers in high pressure (> 30 bar) oxygen lines in case of combustion.

For additional information on compatibility refer to ISO 11114.

10.6. Hazardous decomposition products

: None.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity	: No known toxicological effects from this product.
Skin corrosion/irritation	: No known effects from this product.
Serious eye damage/irritation	: No known effects from this product.
Respiratory or skin sensitisation	: No known effects from this product.
Germ cell mutagenicity	: No known effects from this product.
Carcinogenicity	: No known effects from this product.
Toxic for reproduction : Fertility	: No known effects from this product.
Toxic for reproduction : unborn child	: No known effects from this product.
STOT-single exposure	: No known effects from this product.
STOT-repeated exposure	: No known effects from this product.
Aspiration hazard	: Not applicable for gases and gas mixtures.

SECTION 12: Ecological information

12.1. Toxicity

Assessment	: No ecological damage caused by this product.
EC50 48h - Daphnia magna [mg/l]	: No data available.
EC50 72h - Algae [mg/l]	: No data available.
LC50 96 h - Fish [mg/l]	: No data available.

12.2. Persistence and degradability

Assessment : No ecological damage caused by this product.

12.3. Bioaccumulative potential

Assessment : No data available.

12.4. Mobility in soil

Assessment : Because of its high volatility, the product is unlikely to cause ground or water pollution.

Partition into soil is unlikely.

12.5. Results of PBT and vPvB assessment

Assessment : No data available.

12.6. Other adverse effects

Other adverse effects : No known effects from this product.

Effect on the ozone layer : None.

Effect on global warming : None.

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Contact supplier if guidance is required.

May be vented to atmosphere in a well ventilated place.

Do not discharge into any place where its accumulation could be dangerous.

Ensure that the emission levels from local regulations or operating permits are not exceeded.

Refer to the EIGA code of practice Doc.30 "Disposal of Gases", downloadable at http://www.eiga.eu for more guidance on suitable disposal methods.

Return unused product in original cylinder to supplier.

List of hazardous waste codes (from Commission Decision 2000/532/EC as amended) : 16 05 04 *: Gases in pressure containers (including halons) containing hazardous substances.

13.2. Additional information

: External treatment and disposal of waste should comply with applicable local and/or national regulations.

SECTION 14: Transport information

14.1. UN number

UN-No. : 1072

14.2. UN proper shipping name

Transport by road/rail (ADR/RID) : OXYGEN, COMPRESSED

Transport by air (ICAO-TI / IATA-DGR) : Oxygen, compressed

Transport by sea (IMDG) : OXYGEN, COMPRESSED

14.3. Transport hazard class(es)

Labelling :

2.2 : Non-flammable, non-toxic gases.

5.1 : Oxidizing substances.

Transport by road/rail (ADR/RID)

Class : 2

Classification code : 1O

Hazard identification number : 25

Tunnel Restriction : E - Passage forbidden through tunnels of category E

Transport by air (ICAO-TI / IATA-DGR)

Class / Div. (Sub. risk(s))	: 2.2 (5.1)

Transport by sea (IMDG)

Class / Div. (Sub. risk(s))	: 2.2 (5.1)
Emergency Schedule (EmS) - Fire	: F-C
Emergency Schedule (EmS) - Spillage	: S-W

14.4. Packing group

Transport by road/rail (ADR/RID)	: Not applicable
Transport by air (ICAO-TI / IATA-DGR)	: Not applicable
Transport by sea (IMDG)	: Not applicable

14.5. Environmental hazards

Transport by road/rail (ADR/RID)	: None.
Transport by air (ICAO-TI / IATA-DGR)	: None.
Transport by sea (IMDG)	: None.

14.6. Special precautions for user

Packing Instruction(s)

Transport by road/rail (ADR/RID)	: P200
Transport by air (ICAO-TI / IATA-DGR)	
Passenger and Cargo Aircraft	: 200.
Cargo Aircraft only	: 200.
Transport by sea (IMDG)	: P200

Special transport precautions : Avoid transport on vehicles where the load space is not separated from the driver's compartment.

Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.

Before transporting product containers:

- Ensure there is adequate ventilation.
- Ensure that containers are firmly secured.
- Ensure cylinder valve is closed and not leaking.
- Ensure valve outlet cap nut or plug (where provided) is correctly fitted.
- Ensure valve protection device (where provided) is correctly fitted.

14.7. Transport in bulk according to Annex II of Marpol and the IBC Code

: Not applicable.

SECTION 15: Regulatory information

15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture

EU-Regulations

Restrictions on use	: None.
Seveso Directive : 2012/18/EU (Seveso III)	: Listed.

National regulations

National legislation	: Ensure all national/local regulations are observed.

15.2. Chemical safety assessment

: A CSA does not need to be carried out for this product.

SECTION 16: Other information

Indication of changes : Revised safety data sheet in accordance with commission regulation (EU) No 2015/830.

Abbreviations and acronyms :
ATE - Acute Toxicity Estimate
CLP - Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008
REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006
EINECS - European Inventory of Existing Commercial Chemical Substances
CAS# - Chemical Abstract Service number
PPE - Personal Protection Equipment
LC50 - Lethal Concentration to 50 % of a test population
RMM - Risk Management Measures
PBT - Persistent, Bioaccumulative and Toxic
vPvB - Very Persistent and Very Bioaccumulative
STOT- SE : Specific Target Organ Toxicity - Single Exposure
CSA - Chemical Safety Assessment
EN - European Standard
UN - United Nations
ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road
IATA - International Air Transport Association
IMDG code - International Maritime Dangerous Goods
RID - Regulations concerning the International Carriage of Dangerous Goods by Rail
WGK - Water Hazard Class
STOT - RE : Specific Target Organ Toxicity - Repeated Exposure

Training advice : Ensure operators understand the hazard of oxygen enrichment.

DISCLAIMER OF LIABILITY : Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out.

Details given in this document are believed to be correct at the time of going to press.

Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

End of document

Air Liquide	**SAFETY DATA SHEET**	Page : 1 Revised edition no : 1 Date of issued :17 / 12 / 2015 Supersedes : 28 / 12 / 2010
C.1.5: Argon	**Argon**	**2010483**

2.2 : Non-flammable, non-toxic gases

Warning

SECTION 1. Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Trade name : Argon, ALPHAGAZ ™ Argon, SMARTOP™ Argon, Purified /Compressed Argon, Blueshield™ Argon, ARCAL™ 1, ARCAL™ Prime

SDS Nr : 2010483

Chemical description : Argon
CAS No :7440-37-1
EC No :231-147-0
Index No :---

Chemical formula : Ar

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

Relevant identified uses : Industrial and professional. Perform risk assessment prior to use.
Test gas/Calibration gas. Laboratory use.
Shield gas for welding processes. Contact supplier for more information on uses.

1.3. Details of the supplier of the safety data sheet

Company identification : AIR LIQUIDE SINGAPORE PTE LTD
HEAD OFFICE : 438B ALEXANDRA ROAD,
BLOCK B, ALEXANDRA TECHNOPARK #07-01
119968 SINGAPORE
SPECIAL GASES OFFICE : NO 24 JALAN BUROH SINGAPORE 619480

1.4. Emergency telephone number

Emergency telephone number : +65 6265 3788, +65 9619 9229 (After Office Hour)

SECTION 2. Hazards identification

2.1. Classification of the substance or mixture

Hazard Class and Category Code Regulation EC 1272/2008 (CLP)

- **Physical hazards** : Gases under pressure - Compressed gas - Warning - (CLP : Press. Gas) - H280

Classification EC 67/548 or EC 1999/45

: Not classified as dangerous substance / mixture.
Not included in Annex VI.
No EC labelling required.

2.2. Label elements

SECTION 2. Hazards identification (continued)

Labelling Regulation EC 1272/2008 (CLP)

- **Hazard pictograms**

- **Hazard pictograms code** : GHS04
- **Signal word** : Warning
- **Hazard statements** : H280 - Contains gas under pressure; may explode if heated.
- **Precautionary statements**
  - **Storage** : P403 - Store in a well-ventilated place.

2.3. Other hazards

: Asphyxiant in high concentrations.

SECTION 3. Composition/information on ingredients

3.1. Substance / 3.2. Mixture

Substance.

Substance name		Contents	CAS No EC No Index No Registration no	Classification(DSD)	Classification(CLP)
Argon	:	100 %	7440-37-1 231-147-0 ----- * 1	Not classified (DSD)	Press. Gas Compressed (H280)

Contains no other components or impurities which will influence the classification of the product.
* 1: Listed in Annex IV / V REACH, exempted from registration.
* 2: Registration deadline not expired.
* 3: Registration not required: Substance manufactured or imported < 1t/y.
Full text of R-phrases see section 16. Full text of H-statements see section 16.

SECTION 4. First aid measures

4.1. Description of first aid measures

First aid measures

- **- Inhalation** : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
- **- Skin contact** : Adverse effects not expected from this product.
- **- Eye contact** : Adverse effects not expected from this product.
- **- Ingestion** : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

: In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/ consciousness. Victim may not be aware of asphyxiation.
Refer to section 11.

4.3. Indication of any immediate medical attention and special treatment needed

: None.

SECTION 4. First aid measures (continued)

SECTION 5. Firefighting measures

5.1. Extinguishing media

Extinguishing media

- Suitable extinguishing media : Water spray or fog.

- Unsuitable extinguishing media : Do not use water jet to extinguish.

5.2. Special hazards arising from the substance or mixture

Specific hazards : Exposure to fire may cause containers to rupture/explode.

Hazardous combustion products : None.

5.3. Advice for fire-fighters

Specific methods : If possible, stop flow of product.
Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas receptacles to rupture. Cool endangered receptacles with water spray jet from a protected position.
Move away from the container and cool with water from a protected position.
Use water spray or fog to knock down fire fumes if possible.

Special protective equipment for fire fighters : Use self-contained breathing apparatus.
Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask.
Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters.
Standard EN 469 - Protective clothing for firefighters. Standard - EN 659: Protective gloves for firefighters.

SECTION 6. Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

: Evacuate area.
Try to stop release.
Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe.
Prevent from entering sewers, basements and workpits, or any place where its accumulation can be dangerous.
Ensure adequate air ventilation.

6.2. Environmental precautions

: Try to stop release.

6.3. Methods and material for containment and cleaning up

: Ventilate area.

6.4. Reference to other sections

: See also sections 8 and 13.

SECTION 7. Handling and storage

7.1. Precautions for safe handling

Safe use of the product : Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Contact your gas supplier if in doubt.
Only experienced and properly instructed persons should handle gases under pressure.
The substance must be handled in accordance with good industrial hygiene and safety procedures.
Do not smoke while handling product.
Ensure the complete gas system was (or is regularily) checked for leaks before use.
Consider pressure relief device(s) in gas installations.

Safe handling of the gas receptacle : Refer to supplier's container handling instructions.
Suck back of water into the container must be prevented.
Do not allow backfeed into the container.
Protect cylinders from physical damage; do not drag, roll, slide or drop.
When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders.
Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use.
If user experiences any difficulty operating cylinder valve discontinue use and contact supplier.
Never attempt to repair or modify container valves or safety relief devices.
Damaged valves should be reported immediately to the supplier.
Keep container valve outlets clean and free from contaminants particularly oil and water.
Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment.
Close container valve after each use and when empty, even if still connected to equipment.
Never attempt to transfer gases from one cylinder/container to another.
Never use direct flame or electrical heating devices to raise the pressure of a container.
Do not remove or deface labels provided by the supplier for the identification of the cylinder contents.
Containers should be stored in the vertical position and properly secured to prevent toppling.

7.2. Conditions for safe storage, including any incompatibilities

: Keep container below 50°C in a well ventilated place.
Observe all regulations and local requirements regarding storage of containers.
Containers should not be stored in conditions likely to encourage corrosion.
Containers should be stored in the vertical position and properly secured to prevent toppling.
Stored containers should be periodically checked for general condition and leakage.
Container valve guards or caps should be in place.
Store containers in location free from fire risk and away from sources of heat and ignition.
Keep away from combustible materials.

7.3. Specific end use(s)

: None.

SECTION 8. Exposure controls/personal protection

8.1. Control parameters

DNEL: Derived no effect level (Workers)

: No data available.

DMEL: Derived mimimum effect level (Workers)

: No data available.

PNEC: Predicted no effect concentration

SECTION 8. Exposure controls/personal protection (continued)

: No data available.

8.2. Exposure controls

8.2.1. Appropriate engineering controls : Oxygen detectors should be used when asphixiating gases may be released.
Systems under pressure shoud be regularily checked for leakages.
Provide adequate general and local exhaust ventilation.
Consider work permit system e.g. for maintenance activities.

8.2.2. Individual protection measures, e.g. personal protective equipment : A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered:
PPE compliant to the recommended EN/ISO standards should be selected.

• Eye/face protection : Wear safety glasses with side shields.
Standard EN 166 - Personal eye-protection.

• Skin protection

- Hand protection : Wear working gloves when handling gas containers.
Standard EN 388 - Protective gloves against mechanical risk.

- Other : Wear safety shoes while handling containers.
Standard EN ISO 20345 - Personal protective equipment - Safety footwear.

• Respiratory protection : None necessary.

• Thermal hazards : None necessary.

8.2.3. Environmental exposure controls : Refer to local regulations for restriction of emissions to the atmosphere. See section 13 for specific methods for waste gas treatment.

SECTION 9. Physical and chemical properties

9.1. Information on basic physical and chemical properties

Appearance

Physical state at 20°C / 101.3kPa : Gas.

Colour : Colourless.

Odour : Odourless.

Odour threshold : Odour threshold is subjective and inadequate to warn for overexposure.

pH value : Not applicable.

Molar mass [g/mol] : 40

Melting point [°C] : -189

Boiling point [°C] : -186

Critical temperature [°C] : -122

Flash point [°C] : Not applicable for gases and gas-mixtures.

Evaporation rate (ether=1) : Not applicable for gases and gas-mixtures.

Flammability range [vol% in air] : Non flammable.

Vapour pressure [20°C] : Not applicable.

Relative density, gas (air=1) : 1.38

Relative density, liquid (water=1) : Not applicable.

Solubility in water [mg/l] : Solubility in water of component(s) of the mixture :
67

Partition coefficient n-octanol/water [log Kow] : Not applicable for inorganic gases.

Viscosity at 20°C [mPa.s] : Not applicable.

Explosive Properties : Not applicable.

SECTION 9. Physical and chemical properties (continued)

Oxidising Properties : None.

9.2. Other information

Other data : Gas/vapour heavier than air. May accumulate in confined spaces, particularly at or below ground level.

SECTION 10. Stability and reactivity

10.1. Reactivity

: No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

: Stable under normal conditions.

10.3. Possibility of hazardous reactions

: None.

10.4. Conditions to avoid

: None under recommended storage and handling conditions (see section 7).

10.5. Incompatible materials

: None.
For additional information on compatibility refer to ISO 11114.

10.6. Hazardous decomposition products

: Under normal conditions of storage and use, hazardous decomposition products should not be produced.

SECTION 11. Toxicological information

11.1. Information on toxicological effects

Toxicity information : No known toxicological effects from this product.
Acute toxicity : No known toxicological effects from this product.
Rat inhalation LC50 [ppm/4h] : No data available.
Skin corrosion/irritation : No known effects from this product.
Serious eye damage/irritation : No known effects from this product.
Respiratory or skin sensitisation : No known effects from this product.
STOT-single exposure : No known effects from this product.
STOT-repeated exposure : No known effects from this product.
Aspiration hazard : Not applicable for gases and gas-mixtures.

SECTION 12. Ecological information

12.1. Toxicity

: No ecological damage caused by this product.

EC50 48h - Daphnia magna [mg/l] : No data available.

EC50 72h Algae [mg/l] : No data available.

LC50-96 h - fish [mg/l] : No data available.

12.2. Persistence and degradability

: No ecological damage caused by this product.

12.3. Bioaccumulative potential

: No ecological damage caused by this product.

12.4. Mobility in soil

: No ecological damage caused by this product.

12.5. Results of PBT and vPvB assessment

: Not classified as PBT or vPvB.

12.6. Other adverse effects

Ecological effects information : None.

Effect on the global warming : None.

SECTION 13. Disposal considerations

13.1. Waste treatment methods

: May be vented to atmosphere in a well ventilated place.
Do not discharge into any place where its accumulation could be dangerous.
Refer to the EIGA code of practice Doc.30 “Disposal of Gases"", downloadable at http://www.eiga.org for more guidance on suitable disposal methods.
Contact supplier if guidance is required.

List of hazardous wastes : 16 05 05: Gases in pressure containers other than those mentioned in 16 05 04.

13.2. Additional information

: None.

SECTION 14. Transport information

UN number : 1006

Labelling ADR, IMDG, IATA

: 2.2 : Non-flammable, non-toxic gases

Land transport (ADR/RID)

H.I. nr : 20

UN proper shipping name : ARGON, COMPRESSED

Transport hazard class(es) : 2

Classification code : 1 A

SECTION 14. Transport information (continued)

Packing group : P200
Packing Instruction(s) : P200
Tunnel Restriction : E : Passage forbidden through tunnels of category E.
Environmental hazards : None.

Sea transport (IMDG)

Proper shipping name : ARGON, COMPRESSED
Class : 2.2
Emergency Schedule (EmS) - Fire : F-C
Emergency Schedule (EmS) - Spillage : S-V
Packing instruction : P200
IMDG-Marine pollutant : -

Air transport (ICAO-TI / IATA-DGR)

Proper shipping name (IATA) : ARGON, COMPRESSED
Class : 2.2
Passenger and Cargo Aircraft : Allowed.
Packing instruction - Passenger and Cargo Aircraft : 200
Cargo Aircraft only : Allowed.
Packing instruction - Cargo Aircraft only : 200

Special precautions for user

: Avoid transport on vehicles where the load space is not separated from the driver's compartment.
Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.
Before transporting product containers:
- Ensure there is adequate ventilation.
- Ensure that containers are firmly secured.
- Ensure cylinder valve is closed and not leaking.
- Ensure valve outlet cap nut or plug (where provided) is correctly fitted.
- Ensure valve protection device (where provided) is correctly fitted.

14.7. Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code : Not applicable.

SECTION 15. Regulatory information

15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture

EU legislation

Restrictions on use : None.
Seveso directive 96/82/EC : Not covered.

National legislation

National legislation : Ensure all national/local regulations are observed.

15.2. Chemical safety assessment

: A CSA does not need to be carried out for this product.

SECTION 15. Regulatory information (continued)

SECTION 16. Other information

Indication of changes	: Revised safety data sheet in accordance with commisssion regulation (EU) No 453/2010.
Training advice	: The hazard of asphyxiation is often overlooked and must be stressed during operator training.
List of full text of H-statements in section 3.	: H280 - Contains gas under pressure; may explode if heated.
Further information	: Classification in accordance with calculation methods of regulation (EC) 1272/2008 CLP / (EC) 1999/45 DPD. This Safety Data Sheet has been established in accordance with the applicable European Union legislation.
DISCLAIMER OF LIABILITY	: Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out. Details given in this document are believed to be correct at the time of going to press. Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

End of document

C.1.6: Water

Water

Safety Data Sheet

according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

Date of issue: 11/15/2013 Revision date: 06/12/2018 Supersedes: 01/25/2017 Version: 1.3

SECTION 1: Identification

1.1. Identification

Product form : Substance

Substance name : Water

CAS-No. : 7732-18-5

Product code : LC26750

Formula : H2O

1.2. Recommended use and restrictions on use

Use of the substance/mixture : For laboratory and manufacturing use only.

Recommended use : Laboratory chemicals

Restrictions on use : Not for food, drug or household use

1.3. Supplier

LabChem Inc
Jackson's Pointe Commerce Park Building 1000, 1010 Jackson's Pointe Court
Zelienople, PA 16063 - USA
T 412-826-5230 - F 724-473-0647
info@labchem.com - www.labchem.com

1.4. Emergency telephone number

Emergency number : CHEMTREC: 1-800-424-9300 or +1-703-741-5970

SECTION 2: Hazard(s) identification

2.1. Classification of the substance or mixture

GHS-US classification

Not classified

2.2. GHS Label elements, including precautionary statements

Not classified as a hazardous chemical.

Other hazards not contributing to the classification : None.

2.4. Unknown acute toxicity (GHS US)

Not applicable

SECTION 3: Composition/Information on ingredients

3.1. Substances

Substance type : Mono-constituent

Name	Product identifier	%	GHS-US classification
Water (Main constituent)	(CAS-No.) 7732-18-5	100	Not classified

Full text of hazard classes and H-statements : see section 16

3.2. Mixtures

Not applicable

SECTION 4: First-aid measures

4.1. Description of first aid measures

First-aid measures general : If you feel unwell, seek medical advice (show the label where possible).

First-aid measures after inhalation : Allow victim to breathe fresh air. Allow the victim to rest. Adverse effects not expected from this product.

First-aid measures after skin contact : Adverse effects not expected from this product. Take off contaminated clothing.

First-aid measures after eye contact : Adverse effects not expected from this product.

First-aid measures after ingestion : Do NOT induce vomiting. Adverse effects not expected from this product.

4.2. Most important symptoms and effects (acute and delayed)

Symptoms/effects : Not expected to present a significant hazard under anticipated conditions of normal use.

4.3. Immediate medical attention and special treatment, if necessary

Treat symptomatically.

SECTION 5: Fire-fighting measures

5.1. Suitable (and unsuitable) extinguishing media

Suitable extinguishing media : Foam. Dry powder. Carbon dioxide. Water spray. Sand.

5.2. Specific hazards arising from the chemical

No additional information available

5.3. Special protective equipment and precautions for fire-fighters

Firefighting instructions : Use water spray or fog for cooling exposed containers. Exercise caution when fighting any chemical fire.

Protection during firefighting : Do not enter fire area without proper protective equipment, including respiratory protection.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

6.1.1. For non-emergency personnel

Emergency procedures : Evacuate unnecessary personnel.

6.1.2. For emergency responders

Protective equipment : Equip cleanup crew with proper protection.

Emergency procedures : Ventilate area.

6.2. Environmental precautions

Prevent entry to sewers and public waters. Notify authorities if liquid enters sewers or public waters.

6.3. Methods and material for containment and cleaning up

Methods for cleaning up : Soak up spills with inert solids, such as clay or diatomaceous earth as soon as possible.

6.4. Reference to other sections

See Heading 8. Exposure controls and personal protection.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Precautions for safe handling : Wash hands and other exposed areas with mild soap and water before eating, drinking or smoking and when leaving work.

7.2. Conditions for safe storage, including any incompatibilities

Storage conditions : Keep container closed when not in use.

Incompatible products : Metallic sodium.

Incompatible materials : Sources of ignition. Direct sunlight.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

No additional information available

8.2. Appropriate engineering controls

Appropriate engineering controls : Provide adequate general and local exhaust ventilation.

8.3. Individual protection measures/Personal protective equipment

Personal protective equipment:

Gloves. Safety glasses.

Hand protection:

Wear protective gloves.

Eye protection:

Chemical goggles or safety glasses

Respiratory protection:

None necessary.

Other information:

Do not eat, drink or smoke during use.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state : Liquid
Color : Colorless
Odor : None.
Odor threshold : No data available
pH : 7
Melting point : 0 °C
Freezing point : No data available
Boiling point : 100 °C
Critical temperature : 374.1 °C
Critical pressure : 218.3 atm
Flash point : No data available
Relative evaporation rate (butyl acetate=1) : No data available
Flammability (solid, gas) : Non flammable.
Vapor pressure : 17.535 mm Hg
Vapor pressure at 50 °C : 92.51 mm Hg
Relative vapor density at 20 °C : No data available
Relative density : 1
Specific gravity / density : 0.99823 g/ml
Molecular mass : 18 g/mol
Solubility : Soluble in acetic acid. Soluble in acetone. Soluble in ammonia. Soluble in ammonium chloride. Soluble in ethanol. Soluble in glycerol. Soluble in hydrochloric acid. Soluble in methanol. Soluble in nitric acid. Soluble in sulfuric acid. Soluble in sodium hydroxide solution. Soluble in propylene glycol.
Log Pow : No data available
Auto-ignition temperature : No data available
Decomposition temperature : No data available
Viscosity, kinematic : 1.004 cSt
Viscosity, dynamic : 1.002 cP
Explosion limits : No data available
Explosive properties : Not applicable.
Oxidizing properties : None.

9.2. Other information

VOC content : 0 %

SECTION 10: Stability and reactivity

10.1. Reactivity

No additional information available

10.2. Chemical stability

Stable under normal conditions.

10.3. Possibility of hazardous reactions

Not established.

10.4. Conditions to avoid

Extremely high or low temperatures.

10.5. Incompatible materials

Metallic sodium.

10.6. Hazardous decomposition products

Hydrogen. oxygen.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Likely routes of exposure : Skin and eye contact

Acute toxicity : Not classified

Water (7732-18-5)	
LD50 oral rat	≥ 90000 mg/kg
ATE US (oral)	90000 mg/kg body weight

Skin corrosion/irritation : Not classified
pH: 7

Serious eye damage/irritation : Not classified
pH: 7

Respiratory or skin sensitization : Not classified

Germ cell mutagenicity : Not classified

Carcinogenicity : Not classified
(Based on available data, the classification criteria are not met)

Reproductive toxicity : Not classified

Specific target organ toxicity – single exposure : Not classified

Specific target organ toxicity – repeated exposure : Not classified

Aspiration hazard : Not classified

Potential Adverse human health effects and symptoms : Based on available data, the classification criteria are not met.

SECTION 12: Ecological information

12.1. Toxicity

No additional information available

12.2. Persistence and degradability

Water (7732-18-5)	
Persistence and degradability	Not established.

12.3. Bioaccumulative potential

Water (7732-18-5)	
Bioaccumulative potential	Not established.

12.4. Mobility in soil

No additional information available

12.5. Other adverse effects

Other information : No other effects known.

SECTION 13: Disposal considerations

13.1. Disposal methods

Waste disposal recommendations : Dispose in a safe manner in accordance with local/national regulations.

SECTION 14: Transport information

Department of Transportation (DOT)

In accordance with DOT

Not regulated

SECTION 15: Regulatory information

15.1. US Federal regulations

Water (7732-18-5)
Listed on the United States TSCA (Toxic Substances Control Act) inventory

All components of this product are listed, or excluded from listing, on the United States Environmental Protection Agency Toxic Substances Control Act (TSCA) inventory

15.2. International regulations

CANADA

No additional information available

EU-Regulations

No additional information available

National regulations

No additional information available

15.3. US State regulations

California Proposition 65 - This product does not contain any substances known to the state of California to cause cancer, developmental and/or reproductive harm

SECTION 16: Other information

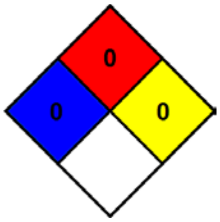
Revision date : 06/12/2018

Other information : None.

NFPA health hazard : 0 - Materials that, under emergency conditions, would offer no hazard beyond that of ordinary combustible materials.

NFPA fire hazard : 0 - Materials that will not burn under typical fire conditions, including intrinsically noncombustible materials such as concrete, stone, and sand.

NFPA reactivity : 0 - Material that in themselves are normally stable, even under fire conditions.



Hazard Rating

Health : 0 Minimal Hazard - No significant risk to health

Flammability : 0 Minimal Hazard - Materials that will not burn

Physical : 0 Minimal Hazard - Materials that are normally stable, even under fire conditions, and will NOT react with water, polymerize, decompose, condense, or self-react. Non-Explosives.

Personal protection : A

A - Safety glasses

SDS US LabChem

C.1.7: Ammonia

Air Liquide	SAFETY DATA SHEET	Page : 1/23 Revised edition no : 1 Compilation date : 5 / 7 / 2018 Supersedes : 26 / 9 / 2017
	Ammonia	**NOAL_0002** Country : SE / Language : EN

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1. Product identifier

Trade name : Ammonia, Anhydrous ammonia, Ammonia N38, Ammonia HG, Ammonia LGC
SDS no : NOAL_0002
Chemical description : Anhydrous ammonia
CAS-No. : 7664-41-7
EC-No. : 231-635-3
EC Index-No. : 007-001-00-5
Registration-No. : 01-2119488876-14
Chemical formula : NH_3

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

Relevant identified uses : Industrial and professional. Perform risk assessment prior to use.
See the list of identified uses and exposure scenarios in the annex of the safety data sheet.
Contact supplier for more information on uses.
Uses advised against : Consumer use.

1.3. Details of the supplier of the safety data sheet

Company identification

AIR LIQUIDE GAS AB
Lundavägen 151
21209 Malmö - SWEDEN
T +46 40 38 10 00
eunordic-sds@airliquide.com

E-Mail address (competent person) : eunordic-sds@airliquide.com

1.4. Emergency telephone number

Emergency telephone number : 112
Availability
(24 / 7)

SECTION 2: Hazards identification

2.1. Classification of the substance or mixture

Classification according to Regulation (EC) No. 1272/2008 [CLP]

Physical hazards	Flammable gases, Category 2	H221
	Gases under pressure : Liquefied gas	H280
Health hazards	Acute toxicity (inhalation:gas) Category 3	H331
	Skin corrosion/irritation, Category 1B	H314
	Serious eye damage/eye irritation, Category 1	H318
Environmental hazards	Hazardous to the aquatic environment — Acute Hazard, Category 1	H400

Hazardous to the aquatic environment — Chronic Hazard, Category 2	H411

2.2. Label elements

Labelling according to Regulation (EC) No. 1272/2008 [CLP]

Hazard pictograms (CLP) :


GHS04


GHS05


GHS06


GHS09

Signal word (CLP) : Danger

Hazard statements (CLP) : H221 - Flammable gas..
H280 - Contains gas under pressure; may explode if heated..
H314 - Causes severe skin burns and eye damage..
H331 - Toxic if inhaled..
H410 - Very toxic to aquatic life with long lasting effects..
EUH071 - Corrosive to the respiratory tract..

Precautionary statements (CLP)

- Prevention : P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking..
P260 - Do not breathe gas, vapours.
P273 - Avoid release to the environment..
P280 - Wear protective gloves, protective clothing, eye protection, face protection..

- Response : P303+P361+P353+P315 - IF ON SKIN : (or hair) Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower. Get immediate medical advice / attention.
P304+P340+P315 - IF INHALED : Remove person to fresh air and keep comfortable for breathing. Get immediate medical advice / attention.
P305+P351+P338+P315 - IF IN EYES : Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Get immediate medical advice / attention.
P377 - Leaking gas fire: Do not extinguish, unless leak can be stopped safely..
P381 - In case of leakage, eliminate all ignition sources..

- Storage : P403 - Store in a well-ventilated place..
P405 - Store locked up..

2.3. Other hazards

: None.

SECTION 3: Composition/information on ingredients

3.1. Substances

Name	Product identifier	Composition [V-%]:	Classification according to Regulation (EC) No. 1272/2008 [CLP]
Anhydrous ammonia	(CAS-No.) 7664-41-7 (EC-No.) 231-635-3 (EC Index-No.) 007-001-00-5 (Registration-No.) 01-2119488876-14	100	Flam. Gas 2, H221 Press. Gas (Liq.), H280 Acute Tox. 3 (Inhalation:gas), H331 Skin Corr. 1B, H314 Eye Dam. 1, H318 Aquatic Acute 1, H400 Aquatic Chronic 2, H411

Contains no other components or impurities which will influence the classification of the product.

3.2. Mixtures

: Not established.

SECTION 4: First aid measures

4.1. Description of first aid measures

- Inhalation : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.
- Skin contact : Remove contaminated clothing. Drench affected area with water for at least 15 minutes.
  In case of frostbite spray with water for at least 15 minutes. Apply a sterile dressing. Obtain medical assistance.
- Eye contact : Immediately flush eyes thoroughly with water for at least 15 minutes.
- Ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

: May cause severe chemical burns to skin and cornea. Suitable first-aid treatment should be immediately available. Seek medical advice before using product.

Prolonged exposure to small concentrations may result in pulmonary oedema.

Material is destructive to tissue of the mucuous membranes and upper respiratory tract. Cough, shortness of breath, headache, nausea.

Refer to section 11.

4.3. Indication of any immediate medical attention and special treatment needed

: Obtain medical assistance.

Treat with corticosteroid spray as soon as possible after inhalation.

SECTION 5: Firefighting measures

5.1. Extinguishing media

- Suitable extinguishing media : Water spray or fog.
  Foam.
- Unsuitable extinguishing media : Carbon dioxide.
  Do not use water jet to extinguish.

5.2. Special hazards arising from the substance or mixture

Specific hazards : Exposure to fire may cause containers to rupture/explode.

Hazardous combustion products : Nitric oxide/nitrogen dioxide.

5.3. Advice for firefighters

Specific methods : Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas receptacles to rupture. Cool endangered receptacles with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems.

If possible, stop flow of product.

Use water spray or fog to knock down fire fumes if possible.

	Do not extinguish a leaking gas flame unless absolutely necessary. Spontaneous/explosive re-ignition may occur. Extinguish any other fire. Move containers away from the fire area if this can be done without risk.
Special protective equipment for fire fighters	: Wear gas tight chemically protective clothing in combination with self contained breathing apparatus. Standard EN 943-2: Protective clothing against liquid and gaseous chemicals, aerosols and solid particles. Gas-tight chemical protective suits for emergency teams. Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

: Try to stop release.

Evacuate area.

Monitor concentration of released product.

Consider the risk of potentially explosive atmospheres.

Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe.

Eliminate ignition sources.

Use chemically protective clothing.

Ensure adequate air ventilation.

Act in accordance with local emergency plan.

Stay upwind.

6.2. Environmental precautions

: Reduce vapour with fog or fine water spray.

Try to stop release.

6.3. Methods and material for containment and cleaning up

: Hose down area with water.

Ventilate area.

Keep area evacuated and free from ignition sources until any spilled liquid has evaporated (ground free from frost).

Wash contaminated equipment or sites of leaks with copious quantities of water.

6.4. Reference to other sections

: See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Safe use of the product	: The product must be handled in accordance with good industrial hygiene and safety procedures. Only experienced and properly instructed persons should handle gases under pressure. Consider pressure relief device(s) in gas installations. Ensure the complete gas system was (or is regularily) checked for leaks before use. Do not smoke while handling product.

Avoid exposure, obtain special instructions before use.

Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Contact your gas supplier if in doubt.

Installation of a cross purge assembly between the cylinder and the regulator is recommended.

Purge system with dry inert gas (e.g. helium or nitrogen) before gas is introduced and when system is placed out of service.

Avoid suck back of water, acid and alkalis.

Assess the risk of potentially explosive atmospheres and the need for explosion-proof equipment.

Purge air from system before introducing gas.

Take precautionary measures against static discharge.

Keep away from ignition sources (including static discharges).

Consider the use of only non-sparking tools.

Do not breathe gas.

Avoid release of product into atmosphere.

Ensure equipment is adequately earthed.

Safe handling of the gas receptacle : Refer to supplier's container handling instructions.

Do not allow backfeed into the container.

Protect cylinders from physical damage; do not drag, roll, slide or drop.

When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders.

Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use.

If user experiences any difficulty operating cylinder valve discontinue use and contact supplier.

Never attempt to repair or modify container valves or safety relief devices.

Damaged valves should be reported immediately to the supplier.

Keep container valve outlets clean and free from contaminants particularly oil and water.

Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment.

Close container valve after each use and when empty, even if still connected to equipment.

Never attempt to transfer gases from one cylinder/container to another.

Never use direct flame or electrical heating devices to raise the pressure of a container.

Do not remove or deface labels provided by the supplier for the identification of the cylinder contents.

Suck back of water into the container must be prevented.

Open valve slowly to avoid pressure shock.

7.2. Conditions for safe storage, including any incompatibilities

: Observe all regulations and local requirements regarding storage of containers.

Containers should not be stored in conditions likely to encourage corrosion.

Container valve guards or caps should be in place.

Containers should be stored in the vertical position and properly secured to prevent them from falling over.

Stored containers should be periodically checked for general condition and leakage.

Keep container below 50°C in a well ventilated place.

Store containers in location free from fire risk and away from sources of heat and ignition.

Keep away from combustible materials.

Segregate from oxidant gases and other oxidants in store.

All electrical equipment in the storage areas should be compatible with the risk of a potentially explosive atmosphere.

7.3. Specific end use(s)

: None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

Anhydrous ammonia (7664-41-7)		
OEL : Occupational Exposure Limits		
EU	TWA IOELV (EU) 8 h [mg/m³]	14 mg/m³
	TWA IOELV (EU) 8 h [ppm]	20 ppm
	STEL IOELV (EU) 15 min [mg/m³]	36 mg/m³
	STEL IOELV (EU) 15 min [ppm]	50 ppm
Sweden	TWA (SV) OEL 8h [mg/m³]	14 mg/m³
	TWA (SV) OEL 8h [ppm]	20 ppm
	STEL (SV) OEL 15min [mg/m³]	36 mg/m³
	STEL (SV) OEL 15min [ppm]	50 ppm
	Anmärkning (SE)	4 (Korttidsgränsvärdet avser en 5-minutersperiod. Detta gäller för ammoniak, diisocyanater, 2,6-diisopropylfenylisocyanat, fenylisocyanat, isocyansyra och metylisocyanat)

Anhydrous ammonia (7664-41-7)	
DNEL: Derived no effect level (Workers)	
Acute - local effects, inhalation	36 mg/m³
Acute - systemic effects, inhalation	47.6 mg/m³
Long-term - local effects, inhalation	14 mg/m³
Long-term - systemic effects, inhalation	47.6 mg/m³
Acute - systemic effects, dermal	6.8 mg/kg bw/day
Long-term - systemic effects, dermal	6.8 mg/kg bw/day

Anhydrous ammonia (7664-41-7)	
PNEC: Predicted no effect concentration	
Aqua (freshwater)	0.0011 mg/l
Aqua (marine water)	0.0011 mg/l

8.2. Exposure controls

8.2.1. Appropriate engineering controls

: Provide adequate general and local exhaust ventilation.

Product to be handled in a closed system.

Systems under pressure should be regularily checked for leakages.

Ensure exposure is below occupational exposure limits (where available).

Gas detectors should be used when toxic gases may be released.

Consider the use of a work permit system e.g. for maintenance activities.

8.2.2. Individual protection measures, e.g. personal protective equipment

: A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered:
PPE compliant to the recommended EN/ISO standards should be selected.

• Eye/face protection : Wear goggles and a face shield when transfilling or breaking transfer connections.
Standard EN 166 - Personal eye-protection - specifications.
Provide readily accessible eye wash stations and safety showers.

• Skin protection

- Hand protection : Wear working gloves when handling gas containers.

Standard EN 388 - Protective gloves against mechanical risk.

Wear cold insulating gloves when transfilling or breaking transfer connections.

Standard EN 511 - Cold insulating gloves.

Wear chemically resistant protective gloves.

Standard EN 374 - Protective gloves against chemicals.

Permeation time: minimum >30min short term exposure: material / thickness Chloroprene rubber (CR) / 0.5 [mm] .

Permeation time: minimum >480min long term exposure : material / thickness Butyl rubber (IIR) / 0.7 [mm].

Consult glove manufacturer´s product information on material suitability and material thickness.

The breakthrough time of the selected gloves must be greater than the intended use period.

- Other : Keep suitable chemically resistant protective clothing readily available for emergency use.
Standard EN943-1 - Full protective suits against liquid, solid and gaseous chemicals.
Wear safety shoes while handling containers.
Standard EN ISO 20345 - Personal protective equipment - Safety footwear.

• Respiratory protection : Gas filters may be used if all surrounding conditions e.g. type and concentration of the contaminant(s) and duration of use are known.
Use gas filters with full face mask, where exposure limits may be exceeded for a short-term period, e.g. connecting or disconnecting containers.
Recommended: Filter K (green).
Gas filters do not protect against oxygen deficiency.
Standard EN 14387 - Gas filter(s), combined filter(s) and full face mask - EN 136.
Keep self contained breathing apparatus readily available for emergency use.
Self contained breathing apparatus is recommended, where unknown exposure may be expected, e.g. during maintenance activities on installation systems.
Standard EN 137 - Self-contained open-circuit compressed air breathing apparatus with full face mask.

• Thermal hazards : None in addition to the above sections.

8.2.3. Environmental exposure controls

: Refer to local regulations for restriction of emissions to the atmosphere. See section 13 for specific methods for waste gas treatment.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Appearance	
• Physical state at 20°C / 101.3kPa	: Gas.
• Colour	: Colourless.
Odour	: Ammoniacal.
Odour threshold	: Odour threshold is subjective and inadequate to warn of overexposure.
pH value	: If dissolved in water pH-value will be affected.
Molar mass	: 17 g/mol
Melting point	: -77.7 °C
Boiling point	: -33 °C
Flash point	: Not applicable for gases and gas mixtures.
Critical temperature [°C]	: 132 °C
Evaporation rate (ether=1)	: Not applicable for gases and gas mixtures.
Flammability range	: 15.4 - 33.6 vol %
Vapour pressure [20°C]	: 8.6 bar(a)
Vapour pressure [50°C]	: 20 bar(a)
Relative density, gas (air=1)	: 0.6

Relative density, liquid (water=1)	: 0.7
Solubility in water	: 517 g/l
Partition coefficient n-octanol/water [log Kow]	: Not applicable for inorganic gases.
Auto-ignition temperature	: 630 °C
Decomposition point [°C]	: Not applicable.
Viscosity [20°C]	: No reliable data available.
Explosive Properties	: Not applicable.
Oxidising Properties	: Not applicable.

9.2. Other information

Other data : No additional information available

SECTION 10: Stability and reactivity

10.1. Reactivity

: No reactivity hazard other than the effects described in sub-sections below.

10.2. Chemical stability

: Stable under normal conditions.

10.3. Possibility of hazardous reactions

: Can form explosive mixture with air.
May react violently with oxidants.

10.4. Conditions to avoid

: Keep away from heat/sparks/open flames/hot surfaces. – No smoking.
Avoid moisture in installation systems.

10.5. Incompatible materials

: Air, Oxidisers.
Reacts with water to form corrosive alkalis.
May react violently with acids.
For additional information on compatibility refer to ISO 11114.

10.6. Hazardous decomposition products

: Under normal conditions of storage and use, hazardous decomposition products should not be produced.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity : Toxic if inhaled.
Inhalation of large amounts leads to bronchospasm, laryngeal oedema and pseudomembrane formation.

LC50 inhalation rat (ppm)	2000 ppm/4h

Skin corrosion/irritation	: Causes severe skin burns and eye damage.
Serious eye damage/irritation	: Causes serious eye damage.
Respiratory or skin sensitisation	: No known effects from this product.
Germ cell mutagenicity	: No known effects from this product.
Carcinogenicity	: No known effects from this product.
Reproductive toxicity	: No known effects from this product. No known effects from this product.
STOT-single exposure	: Severe corrosion to the respiratory tract at high concentrations.

May cause inflammation of the respiratory system.

Target organ(s) : Respiratory tract.

STOT-repeated exposure : No known effects from this product.

Aspiration hazard : Not applicable for gases and gas mixtures.

SECTION 12: Ecological information

12.1. Toxicity

Assessment : Very toxic to aquatic life.
Toxic to aquatic life with long lasting effects.

EC50 48h - Daphnia magna [mg/l] : 101 mg/l
EC50 72h - Algae [mg/l] : No data available.
LC50 96 h - Fish [mg/l] : 0.89 mg/l

12.2. Persistence and degradability

Assessment : The substance is biodegradable. Unlikely to persist.

12.3. Bioaccumulative potential

Assessment : No data available.

12.4. Mobility in soil

Assessment : Because of its high volatility, the product is unlikely to cause ground or water pollution.
Partition into soil is unlikely.

12.5. Results of PBT and vPvB assessment

Assessment : Not classified as PBT or vPvB.

12.6. Other adverse effects

Other adverse effects : May cause pH changes in aqueous ecological systems.
Effect on the ozone layer : None.
Effect on global warming : No known effects from this product.

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Contact supplier if guidance is required.

Must not be discharged to atmosphere.

Toxic and corrosive gases formed during combustion should be scrubbed before discharge to atmosphere.

Gas may be scrubbed in sulphuric acid solution.

Gas may be scrubbed in water.

Ensure that the emission levels from local regulations or operating permits are not exceeded.

Refer to the EIGA code of practice Doc.30 "Disposal of Gases", downloadable at http://www.eiga.org for more guidance on suitable disposal methods.

Return unused product in original cylinder to supplier.

List of hazardous waste codes (from Commission Decision 2001/118/EC) : 16 05 04 *: Gases in pressure containers (including halons) containing dangerous substances.

13.2. Additional information

: External treatment and disposal of waste should comply with applicable local and/or national regulations.

SECTION 14: Transport information

14.1. UN number

UN-No. : 1005

14.2. UN proper shipping name

Transport by road/rail (ADR/RID) : AMMONIA, ANHYDROUS
Transport by air (ICAO-TI / IATA-DGR) : Ammonia, anhydrous
Transport by sea (IMDG) : AMMONIA, ANHYDROUS

14.3. Transport hazard class(es)

Labelling :

2.3 : Toxic gases.
8 : Corrosive substances.
Environmentally hazardous substances

Transport by road/rail (ADR/RID)

Class : 2.
Classification code : 2TC.
Hazard identification number : 268.
Tunnel Restriction : C/D - Tank carriage : Passage forbidden through tunnels of category C, D and E. Other carriage : Passage forbidden through tunnels of category D and E.

Transport by sea (IMDG)

Class / Div. (Sub. risk(s)) : 2.3 (8)
Emergency Schedule (EmS) - Fire : F-C.
Emergency Schedule (EmS) - Spillage : S-U.

14.4. Packing group

Transport by road/rail (ADR/RID) : Not established.
Transport by air (ICAO-TI / IATA-DGR) : Not established.
Transport by sea (IMDG) : Not established.

14.5. Environmental hazards

Transport by road/rail (ADR/RID) : Environmentally hazardous substance / mixture.

Transport by air (ICAO-TI / IATA-DGR) : Environmentally hazardous substance / mixture.

Transport by sea (IMDG) : Marine pollutant

14.6. Special precautions for user

Packing Instruction(s)

Transport by road/rail (ADR/RID) : P200.

Transport by air (ICAO-TI / IATA-DGR)

- Passenger and Cargo Aircraft : Forbidden.
- Cargo Aircraft only : Forbidden.

Transport by sea (IMDG) : P200.

Special transport precautions : Avoid transport on vehicles where the load space is not separated from the driver's compartment.

Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.

Before transporting product containers:

- Ensure there is adequate ventilation.
- Ensure that containers are firmly secured.
- Ensure cylinder valve is closed and not leaking.
- Ensure valve outlet cap nut or plug (where provided) is correctly fitted.
- Ensure valve protection device (where provided) is correctly fitted.

14.7. Transport in bulk according to Annex II of Marpol and the IBC Code

: Not applicable.

SECTION 15: Regulatory information

15.1. Safety, health and environmental regulations/legislation specific for the substance or mixture

EU-Regulations

Restrictions on use : None.

Seveso Directive : 2012/18/EU (Seveso III) : Listed.

National regulations

National legislation : Ensure all national/local regulations are observed.

15.2. Chemical safety assessment

A CSA has been carried out.

SECTION 16: Other information

Indication of changes : Revised safety data sheet in accordance with commission regulation (EU) No 453/2010.

Abbreviations and acronyms : ATE - Acute Toxicity Estimate

CLP - Classification Labelling Packaging Regulation; Regulation (EC) No 1272/2008

REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (EC) No 1907/2006

EINECS - European Inventory of Existing Commercial Chemical Substances
CAS# - Chemical Abstract Service number
PPE - Personal Protection Equipment
LC50 - Lethal Concentration to 50 % of a test population
RMM - Risk Management Measures
PBT - Persistent, Bioaccumulative and Toxic
vPvB - Very Persistent and Very Bioaccumulative
STOT- SE : Specific Target Organ Toxicity - Single Exposure
CSA - Chemical Safety Assessment
EN - European Standard
UN - United Nations
ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road
IATA - International Air Transport Association
IMDG code - International Maritime Dangerous Goods
RID - Regulations concerning the International Carriage of Dangerous Goods by Rail
WGK - Water Hazard Class
STOT - RE : Specific Target Organ Toxicity - Repeated Exposure

Training advice : Users of breathing apparatus must be trained.
Ensure operators understand the flammability hazard.
Ensure operators understand the toxicity hazard.

Full text of H- and EUH-statements

Acute Tox. 3 (Inhalation:gas)	Acute toxicity (inhalation:gas) Category 3
Aquatic Acute 1	Hazardous to the aquatic environment — Acute Hazard, Category 1
Aquatic Chronic 2	Hazardous to the aquatic environment — Chronic Hazard, Category 2
Eye Dam. 1	Serious eye damage/eye irritation, Category 1
Flam. Gas 2	Flammable gases, Category 2
Press. Gas (Liq.)	Gases under pressure : Liquefied gas
Skin Corr. 1B	Skin corrosion/irritation, Category 1B
H221	Flammable gas.
H280	Contains gas under pressure; may explode if heated.
H314	Causes severe skin burns and eye damage.
H318	Causes serious eye damage.
H331	Toxic if inhaled.
H400	Very toxic to aquatic life.
H411	Toxic to aquatic life with long lasting effects.
EUH071	Corrosive to the respiratory tract.

DISCLAIMER OF LIABILITY : Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out.
Details given in this document are believed to be correct at the time of going to press.
Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

1. Exposure scenario EIGA002-1

Industrial uses, closed contained conditions

ES Ref.: EIGA002-1
ES Type: Worker - EIGA
Revision date: 25/04/2017

Use descriptors	SU3 PROC1, PROC2, PROC3, PROC4, PROC8b, PROC9 ERC1, ERC2, ERC4, ERC6a, ERC6b, ERC7
Processes, tasks, activities covered	Industrial uses, including product transfers and associated laboratory activities within different closed or contained systems
Assessment method	ECETOC TRA 2.0 EUSES

2. Operational conditions and risk management measures

1.2.1 Contributing scenario controlling environmental exposure (ERC1)

Manufacture of substances	
ERC1	Manufacture of substances
Assessment method	EUSES

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	Annual site tonnage:	950000 t/yr
	Regional use tonnage:	6500000 t/yr
Frequency and duration of use	Emission Days (days/year)	330
Environmental factors not influenced by risk management	Flow rate of receiving water at least:	18000 m³/d
	Dilution of STP emissions at least:	10
Other given operational conditions affecting environmental exposure	Closed systems are used in order to prevent unintended emissions	

Risk Management Measures

Technical onsite conditions and measures to reduce or limit discharges, air emissions and releases to soil	Use appropriate air emissions abatement systems (e.g. wet or dry scrubber or local STP) to ensure that the emission levels defined by local regulations are not exceeded	
	Soil emission controls are not applicable as there is no direct release to soil	
Organisation measures to prevent/limit release from site	Ensure operatives are trained to minimise releases	
Conditions and measures related to sewage treatment plant	Direct emissions to the municipal STP should not be made.	
Conditions and measures related to external treatment of waste for disposal	See section 13 of the SDS	

1.2.2 Contributing scenario controlling environmental exposure (ERC2)

Formulation of preparations	
ERC2	Formulation of preparations
Assessment method	EUSES

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	Annual site tonnage:	1000000 t/yr
	Regional use tonnage:	3800000 t/yr

Frequency and duration of use	Emission Days (days/year)	330
Environmental factors not influenced by risk management	Flow rate of receiving water at least:	18000 m³/d
	Dilution of STP emissions at least:	10
Other given operational conditions affecting environmental exposure	Closed systems are used in order to prevent unintended emissions	

Risk Management Measures

Technical onsite conditions and measures to reduce or limit discharges, air emissions and releases to soil	Use appropriate air emissions abatement systems (e.g. wet or dry scrubber or local STP) to ensure that the emission levels defined by local regulations are not exceeded	
	Soil emission controls are not applicable as there is no direct release to soil	
Organisation measures to prevent/limit release from site	Ensure operatives are trained to minimise releases	
Conditions and measures related to sewage treatment plant	Direct emissions to the municipal STP should not be made.	
Conditions and measures related to external treatment of waste for disposal	See section 13 of the SDS	

1.2.3 Contributing scenario controlling environmental exposure (ERC4)

Industrial use of processing aids in processes and products, not becoming part of articles	
ERC4	Industrial use of processing aids in processes and products, not becoming part of articles

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	Annual site tonnage:	25000 t/yr
	Regional use tonnage:	354000 t/yr
Frequency and duration of use	Emission Days (days/year)	330
Environmental factors not influenced by risk management	Flow rate of receiving water at least:	18000 m³/d
	Dilution of STP emissions at least:	10
Other given operational conditions affecting environmental exposure	Closed systems are used in order to prevent unintended emissions	

Risk Management Measures

Technical onsite conditions and measures to reduce or limit discharges, air emissions and releases to soil	Use appropriate air emissions abatement systems (e.g. wet or dry scrubber or local STP) to ensure that the emission levels defined by local regulations are not exceeded	
	Soil emission controls are not applicable as there is no direct release to soil	
Organisation measures to prevent/limit release from site	Ensure operatives are trained to minimise releases	
Conditions and measures related to sewage treatment plant	Direct emissions to the municipal STP should not be made.	
Conditions and measures related to external treatment of waste for disposal	See section 13 of the SDS	

1.2.4 Contributing scenario controlling environmental exposure (ERC6a)

Industrial use resulting in manufacture of another substance (use of intermediates)	
ERC6a	Industrial use resulting in manufacture of another substance (use of intermediates)
Assessment method	EUSES

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	Annual site tonnage:	800000 t/yr
	Regional use tonnage:	3800000 t/yr
Frequency and duration of use	Emission Days (days/year)	330
Environmental factors not influenced by risk management	Flow rate of receiving water at least:	18000 m³/d
	Dilution of STP emissions at least:	10
Other given operational conditions affecting environmental exposure	Closed systems are used in order to prevent unintended emissions	

Risk Management Measures

Technical onsite conditions and measures to reduce or limit discharges, air emissions and releases to soil	Use appropriate air emissions abatement systems (e.g. wet or dry scrubber or local STP) to ensure that the emission levels defined by local regulations are not exceeded	
	Soil emission controls are not applicable as there is no direct release to soil	
Organisation measures to prevent/limit release from site	Ensure operatives are trained to minimise releases	
Conditions and measures related to sewage treatment plant	Direct emissions to the municipal STP should not be made.	
Conditions and measures related to external treatment of waste for disposal	See section 13 of the SDS	

1.2.5 Contributing scenario controlling environmental exposure (ERC6b)

Industrial use of reactive processing aids	
ERC6b	Industrial use of reactive processing aids

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	Annual site tonnage:	25000 t/yr
	Regional use tonnage:	354000 t/yr
Frequency and duration of use	Emission Days (days/year)	330
Environmental factors not influenced by risk management	Flow rate of receiving water at least:	18000 m³/d
	Dilution of STP emissions at least:	10
Other given operational conditions affecting environmental exposure	Closed systems are used in order to prevent unintended emissions	

Risk Management Measures

Technical onsite conditions and measures to reduce or limit discharges, air emissions and releases to soil	Use appropriate air emissions abatement systems (e.g. wet or dry scrubber or local STP) to ensure that the emission levels defined by local regulations are not exceeded	
	Soil emission controls are not applicable as there is no direct release to soil	
Organisation measures to prevent/limit release from site	Ensure operatives are trained to minimise releases	
Conditions and measures related to sewage treatment plant	Direct emissions to the municipal STP should not be made.	
Conditions and measures related to external treatment of waste for disposal	See section 13 of the SDS	

1.2.6 Contributing scenario controlling environmental exposure (ERC7)

Industrial use of substances in closed systems	
ERC7	Industrial use of substances in closed systems

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	Annual site tonnage:	25000 t/yr
	Regional use tonnage:	354000 t/yr
Frequency and duration of use	Emission Days (days/year)	330
Environmental factors not influenced by risk management	Flow rate of receiving water at least:	18000 m^3/d
	Dilution of STP emissions at least:	10
Other given operational conditions affecting environmental exposure	Closed systems are used in order to prevent unintended emissions	

Risk Management Measures

Technical onsite conditions and measures to reduce or limit discharges, air emissions and releases to soil	Use appropriate air emissions abatement systems (e.g. wet or dry scrubber or local STP) to ensure that the emission levels defined by local regulations are not exceeded	
	Soil emission controls are not applicable as there is no direct release to soil	
Organisation measures to prevent/limit release from site	Ensure operatives are trained to minimise releases	
Conditions and measures related to sewage treatment plant	Direct emissions to the municipal STP should not be made.	
Conditions and measures related to external treatment of waste for disposal	See section 13 of the SDS	

1.2.7 Contributing scenario controlling worker exposure (PROC1)

Use in closed process, no likelihood of exposure	
PROC1	Use in closed process, no likelihood of exposure

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	
Conditions and measures related to personal protection, hygiene and health evaluation	See section 8 of the SDS.	

1.2.8 Contributing scenario controlling worker exposure (PROC2)

Use in closed, continuous process with occasional controlled exposure	
PROC2	Use in closed, continuous process with occasional controlled exposure

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	
	During indoor processes or in cases where natural ventilation is not sufficient, LEV should be in place at points were emissions could occur. Outdoor, LEV is not generally required.	
	Ensure samples are obtained under containment or extract ventilation.	
	Drain down and flush system prior to equipment break-in or maintenance.	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	
Conditions and measures related to personal protection, hygiene and health evaluation	Use suitable eye protection. Wear suitable face shield. Wear suitable coveralls to prevent exposure to the skin	Personal protection measures have to be applied in case of potential exposure only.
	Wear gloves providing a minimum efficiency of (%):	90
	Wear a respirator providing a minimum efficiency of (%):	95 Mandatory if activities take place outdoors or indoors with no local exhaust ventilation
	See section 8 of the SDS.	

1.2.9 Contributing scenario controlling worker exposure (PROC3)

Use in closed batch process (synthesis or formulation)	
PROC3	Use in closed batch process (synthesis or formulation)

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	
	During indoor processes or in cases where natural ventilation is not sufficient, LEV should be in place at points were emissions could occur. Outdoor, LEV is not generally required.	
	Ensure samples are obtained under containment or extract ventilation.	
	Drain down and flush system prior to equipment break-in or maintenance.	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	
Conditions and measures related to personal protection, hygiene and health evaluation	Use suitable eye protection. Wear suitable face shield. Wear suitable coveralls to prevent exposure to the skin	Personal protection measures have to be applied in case of potential exposure only.
	Wear gloves providing a minimum efficiency of (%):	90
	Wear a respirator providing a minimum efficiency of (%):	95 Mandatory if activities take place outdoors or indoors with no local exhaust ventilation
	See section 8 of the SDS.	

1.2.10 Contributing scenario controlling worker exposure (PROC4)

Use in batch and other process (synthesis) where opportunity for exposure arises	
PROC4	Use in batch and other process (synthesis) where opportunity for exposure arises

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	
	During indoor processes or in cases where natural ventilation is not sufficient, LEV should be in place at points were emissions could occur. Outdoor, LEV is not generally required.	
	Ensure samples are obtained under containment or extract ventilation.	
	Drain down and flush system prior to equipment break-in or maintenance.	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	

Conditions and measures related to personal protection, hygiene and health evaluation	Use suitable eye protection. Wear suitable face shield. Wear suitable coveralls to prevent exposure to the skin	Personal protection measures have to be applied in case of potential exposure only.
	Wear gloves providing a minimum efficiency of (%):	90
	Wear a respirator providing a minimum efficiency of (%):	95 Mandatory if activities take place outdoors or indoors with no local exhaust ventilation
	See section 8 of the SDS.	

1.2.11 Contributing scenario controlling worker exposure (PROC8b)

Transfer of substance or preparation (charging/discharging) from/to vessels/large containers at dedicated facilities	
PROC8b	Transfer of substance or preparation (charging/discharging) from/to vessels/large containers at dedicated facilities

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	
	During indoor processes or in cases where natural ventilation is not sufficient, LEV should be in place at points were emissions could occur. Outdoor, LEV is not generally required.	
	Fill containers at dedicated fill points supplied with local extract ventilation.	
	Drain down and flush system prior to equipment break-in or maintenance.	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	
Conditions and measures related to personal protection, hygiene and health evaluation	Use suitable eye protection. Wear suitable face shield. Wear suitable coveralls to prevent exposure to the skin	Personal protection measures have to be applied in case of potential exposure only.
	Wear gloves providing a minimum efficiency of (%):	90
	Wear a respirator providing a minimum efficiency of (%):	95 Mandatory if activities take place outdoors or indoors with no local exhaust ventilation
	See section 8 of the SDS.	

1.2.12 Contributing scenario controlling worker exposure (PROC9)

Transfer of substance or preparation into small containers (dedicated filling line, including weighing)	
PROC9	Transfer of substance or mixture into small containers (dedicated filling line, including weighing)

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information

Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	
	During indoor processes or in cases where natural ventilation is not sufficient, LEV should be in place at points were emissions could occur. Outdoor, LEV is not generally required.	
	Fill containers at dedicated fill points supplied with local extract ventilation.	
	Drain down and flush system prior to equipment break-in or maintenance.	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	
Conditions and measures related to personal protection, hygiene and health evaluation	Use suitable eye protection. Wear suitable face shield. Wear suitable coveralls to prevent exposure to the skin	Personal protection measures have to be applied in case of potential exposure only.
	Wear gloves providing a minimum efficiency of (%):	90
	Wear a respirator providing a minimum efficiency of (%):	95 Mandatory if activities take place outdoors or indoors with no local exhaust ventilation
	See section 8 of the SDS.	

3. Exposure estimation and reference to its source

3.1. Health

3.2. Environment

4. Guidance to Downstream User to evaluate whether he works inside the boundaries set by the ES

4.1. Health

Guidance - Health	Guidance is based on assumed operating conditions which may not be applicable to all sites; thus, scaling may be necessary to define appropriate site-specific risk management measures. For scaling see : . http://www.ecetoc.org/tra

4.2. Environment

Guidance - Environment	Guidance is based on assumed operating conditions which may not be applicable to all sites; thus, scaling may be necessary to define appropriate site-specific risk management measures. For scaling see : . https://ec.europa.eu/jrc/en/scientific-tool/european-union-system-evaluation-substances

1. Exposure scenario EIGA002-2

Professional uses

ES Ref.: EIGA002-2 ES Type: Worker - EIGA Revision date: 25/04/2017	

Use descriptors	SU22 PROC4, PROC8a ERC9a, ERC9b
Processes, tasks, activities covered	Professional uses, including transfer of product in non-industrial settings
Assessment method	ECETOC TRA 2.0

2. Operational conditions and risk management measures

1.2.1 Contributing scenario controlling environmental exposure (ERC9a, ERC9b)

Wide dispersive indoor use of substances in closed systems, Wide dispersive outdoor use of substances in closed systems	
ERC9a	Wide dispersive indoor use of substances in closed systems
ERC9b	Wide dispersive outdoor use of substances in closed systems

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	No additional information	
Other given operational conditions affecting environmental exposure	Closed systems are used in order to prevent unintended emissions	

Risk Management Measures

Organisation measures to prevent/limit release from site	Ensure operatives are trained to minimise exposure	
Conditions and measures related to sewage treatment plant	No additional information	
Conditions and measures related to external treatment of waste for disposal	See section 13 of the SDS	

1.2.2 Contributing scenario controlling worker exposure (PROC4)

Use in batch and other process (synthesis) where opportunity for exposure arises	
PROC4	Use in batch and other process (synthesis) where opportunity for exposure arises

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	

	During indoor processes or in cases where natural ventilation is not sufficient, LEV should be in place at points were emissions could occur. Outdoor, LEV is not generally required.	
	Drain down and flush system prior to equipment break-in or maintenance.	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	
Conditions and measures related to personal protection, hygiene and health evaluation	Use suitable eye protection. Wear suitable face shield. Wear suitable coveralls to prevent exposure to the skin	Personal protection measures have to be applied in case of potential exposure only.
	Wear gloves providing a minimum efficiency of (%):	90
	Wear a respirator providing a minimum efficiency of	95 Mandatory if activities take place outdoors or indoors with no local exhaust ventilation
	See section 8 of the SDS.	

1.2.3 Contributing scenario controlling worker exposure (PROC8a)

Transfer of substance or preparation (charging/discharging) from/to vessels/large containers at non dedicated facilities	
PROC8a	Transfer of substance or preparation (charging/discharging) from/to vessels/large containers at non dedicated facilities

Product characteristics

Physical form of product	See section 9 of the SDS, No additional information
Concentration of substance in product	<= 100 %

Operational conditions

Amounts used	The actual tonnage handled per shift is not considered to influence the exposure as such for this scenario. Instead, the combination of the scale of operation (industrial vs. professional) and level of containment/automation (as reflected in the PROCs and technical conditions) is the main determinant of the process-intrinsic emission potential.	
Frequency and duration of use	Exposure duration	<= 8 h/day
	Covers frequency up to:	5 days/week
Other given operational conditions affecting workers exposure	Indoor or outdoor use	

Risk Management Measures

Technical conditions and measures at process level (source) to prevent release	Handle product within a closed system	
	During indoor processes or in cases where natural ventilation is not sufficient, LEV should be in place at points were emissions could occur. Outdoor, LEV is not generally required.	
	Drain down and flush system prior to equipment break-in or maintenance.	
	Apply a good standard of general or controlled ventilation when maintenance activities are carried out.	
Organisational measures to prevent /limit releases, dispersion and exposure	Ensure operatives are trained to minimise exposure	
	Ensure supervision is in place to check that the RMMs are in place and are being used correctly and that the OCs are being followed	
Conditions and measures related to personal protection, hygiene and health evaluation	Use suitable eye protection. Wear suitable face shield. Wear suitable coveralls to prevent exposure to the skin	Personal protection measures have to be applied in case of potential exposure only.
	Wear gloves providing a minimum efficiency of (%):	90

	Wear a respirator providing a minimum efficiency of	95 Mandatory if activities take place outdoors or indoors with no local exhaust ventilation
	See section 8 of the SDS.	

3. Exposure estimation and reference to its source

3.1. Health

3.2. Environment

4. Guidance to Downstream User to evaluate whether he works inside the boundaries set by the ES

4.1. Health

Guidance - Health	Guidance is based on assumed operating conditions which may not be applicable to all sites; thus, scaling may be necessary to define appropriate site-specific risk management measures. For scaling see : . http://www.ecetoc.org/tra

4.2. Environment

Guidance - Environment	Check that RMMs and OCs are as described above or of equivalent efficiency

Appendix D: Extended Financial Information

Process Title: **Green Ammonia**
Product: **Ammonia**
Plant Site Location: **SW Norway**
Site Factor: **1.00**
Operating Hours per Year: **8400**
Operating Days Per Year: **350**
Operating Factor: **0.9589**

Product Information

This Process will Yield

2	ton of Ammonia per hour
46	ton of Ammonia per day
16,178	ton of Ammonia per year

Price **$550.00** **/ton**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 20 year MACRS	Product Price
2020	Design		0.0%		
2021	Construction	100%	0.0%		
2022	Production	0%	45.0%	3.75%	$550.00
2023	Production	0%	67.5%	7.22%	$569.25
2024	Production	0%	90.0%	6.68%	$589.17
2025	Production		90.0%	6.18%	$609.79
2026	Production		90.0%	5.71%	$631.14
2027	Production		90.0%	5.29%	$653.23
2028	Production		90.0%	4.89%	$676.09
2029	Production		90.0%	4.52%	$699.75
2030	Production		90.0%	4.46%	$724.24
2031	Production		90.0%	4.46%	$749.59
2032	Production		90.0%	4.46%	$775.83
2033	Production		90.0%	4.46%	$802.98
2034	Production		90.0%	4.46%	$831.09
2035	Production		90.0%	4.46%	$860.18
2036	Production		90.0%	4.46%	$890.28

Equipment Costs

Equipment Description		Bare Module Cost
Haber Bosch Reactor	Process Machinery	$340,823
Sodium Doped Iron Catalyst	Catalysts	$20,000
HB-CP-01	Process Machinery	$30,146
HB-CP-02	Process Machinery	$3,021,123
HB-HXA-01	Process Machinery	$127,161
HB-HXA-02	Process Machinery	$105,901
HB-HXA-03	Process Machinery	$153,087
HB-HXA-04	Process Machinery	$120,435
#REF!	#REF!	#REF!
HB-S-01	Process Machinery	$66,024
HB-S-02	Process Machinery	$57,136
Storage Tank	Storage	$940,000
SOEC	Process Machinery	$15,000,000
UP-EM-01	Process Machinery	$5,720
UP-PM-01	Process Machinery	$42,068
#REF!	#REF!	#REF!
#REF!	#REF!	#REF!
UP-CP-01	Process Machinery	$479,984
UP-CP-02	Process Machinery	$525,826
UP-CP-03	Process Machinery	$504,596
UP-CP-04	Process Machinery	$55,437
UP-HX-01	Process Machinery	$108,504
UP-HX-02	Process Machinery	$148,064
UP-CO-01	Process Machinery	$45,449
UP-CO-02	Process Machinery	$39,081
UP-CO-03	Process Machinery	$46,168
UP-CD-01	Process Machinery	$150,110
M6 Filter	Process Machinery	$8,000
Ion Exchange Unit	Process Machinery	$300,000
Total		***#REF!***

Raw Materials

	Raw Material:	Unit:	Required Ratio:		Cost of Raw Material:	
1	Water	ton	1.5	ton per ton of Ammonia	$0.000E+00	per ton
2	Air	ton	1	ton per ton of Ammonia	$0.00	per ton

Total Weighted Average: $0.000E+00 per ton of Ammonia

Byproducts

	Byproduct:	Unit:	Ratio to Product		Byproduct Selling Price	
1	Oxygen	kg	220	kg per ton of Ammonia	$0.200	per kg

Total Weighted Average: $44.000 per ton of Ammonia

Utilities

	Utility:	Unit:	Required Ratio		Utility Cost	
1	High Pressure Steam	MT	0	MT per ton of Ammonia	$0.000E+00	per MT
2	Low Pressure Steam	MT	0	MT per ton of Ammonia	$0.000E+00	per MT
3	Process Water	gal	0	gal per ton of Ammonia	$0.000E+00	per gal
4	Cooling Water	MT	17.340462	MT per ton of Ammonia	$0.027	per MT
5	Chilled Water	MT	71.023798	MT per ton of Ammonia	$1.500	per MT

Total Weighted Average: $107.004 per ton of Ammonia

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	⇨	**30**	**Days**
Cash Reserves (excluding Raw Materials)	⇨	**30**	**Days**
Accounts Payable	⇨	**30**	**Days**
Ammonia Inventory	⇨	**3**	**Days**
Raw Materials	⇨	**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:	**0.50%**	**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:	**5**	**(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:	**$7,920.00**	**per year, for each Operator per Shift**
Control Laboratory:	**$11,700.00**	**per year, for each Operator per Shift**

Maintenance

Wages and Benefits:	**2.00%**	**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):	**$0**
Licensing Fees:	**$0**
Miscellaneous:	**$0**

Depletion Allowance

Annual Depletion Allowance:	**$0**

Variable Cost Summary

Variable Costs at 100% Capacity:

General Expenses

Selling / Transfer Expenses:	$	266,944
Direct Research:	$	427,110
Allocated Research:	$	44,491
Administrative Expense:	$	177,962
Management Incentive Compensation:	$	111,227
Total General Expenses	$	1,027,733

Raw Materials	$0.00	per ton of Ammonia	$0
Byproducts	$44.00	per ton of Ammonia	($711,850)
Utilities	$107.00	per ton of Ammonia	$1,731,152
Total Variable Costs		**$**	**2,047,035**

Fixed Cost Summary

Operations

Direct Wages and Benefits	$	2,080,000
Direct Salaries and Benefits	$	312,000
Operating Supplies and Services	$	124,800
Technical Assistance to Manufacturing	$	198,000
Control Laboratory	$	292,500
Total Operations	**$**	**3,007,300**

Maintenance

Wages and Benefits	$	636,072
Salaries and Benefits	$	159,018
Materials and Services	$	636,072
Maintenance Overhead	$	31,804
Total Maintenance	**$**	**1,462,966**

Operating Overhead

General Plant Overhead:	$	226,283
Mechanical Department Services:	$	76,490
Employee Relations Department:	$	188,038
Business Services:	$	235,845
Total Operating Overhead	**$**	**726,657**

Property Taxes and Insurance

Property Taxes and Insurance:	$	636,072

Other Annual Expenses

Rental Fees (Office and Laboratory Space):	$	-
Licensing Fees:	$	-
Miscellaneous:	$	-
Total Other Annual Expenses	**$**	**-**
Total Fixed Costs	**$**	**5,832,994**

Investment Summary

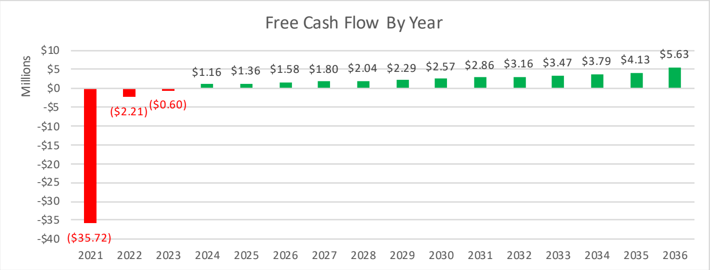
Total Bare Module Costs:				
Fabricated Equipment	$	-		
Process Machinery	$	23,542,003		
Spares	$	-		
Storage	$	940,000		
Other Equipment	$	-		
Catalysts	$	20,000		
Computers, Software, Etc.	$	-		
Total Bare Module Costs:			**$**	**24,502,003**
Direct Permanent Investment				
Cost of Site Preparations:	$	1,225,100		
Cost of Service Facilities:	$	1,225,100		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			**$**	**26,952,203**
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	4,851,397		
Total Depreciable Capital			**$**	**31,803,600**
Total Permanent Investment				
Cost of Land:	$	159,018		
Cost of Royalties:	$	-		
Cost of Plant Start-Up:	$	3,180,360		
Total Permanent Investment - Unadjusted			$	35,142,978
Site Factor				1.00
Total Permanent Investment			**$**	**35,142,978**

Working Capital

		2021		2022		2023
Accounts Receivable	$	329,109	$	164,554	$	164,554
Cash Reserves	$	279,770	$	139,885	$	139,885
Accounts Payable	$	(64,029)	$	(32,014)	$	(32,014)
Ammonia Inventory	$	32,911	$	16,455	$	16,455
Raw Materials	$	-	$	-	$	-
Total	**$**	**577,760**	**$**	**288,880**	**$**	**288,880**
Present Value at 10%	*$*	*525,237*	*$*	*238,744*	*$*	*217,040*
Total Capital Investment			**$**	**36,123,998**		

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Total Costs	20 year MACRS	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 10%
2020	0%		-	-	-	-	-	0.00%	-	-	-	-	-	-	-	-
2021	0%		-	(35,143,000)	(577,800)	-	-	0.00%	-	-	-	-	-	-	(35,720,700)	(32,473,400)
2022	45%	$550.00	4,004,200	-	(288,900)	(921,200)	(6,754,160)	3.75%	(5,833,000)	(1,192,600)	-	(3,942,600)	828,000	(3,114,700)	(2,210,900)	(34,300,600)
2023	68%	$569.25	6,216,400	-	(288,900)	(1,381,700)	(7,214,743)	7.22%	(5,833,000)	(2,295,900)	-	(3,294,200)	691,800	(2,602,400)	(595,400)	(34,747,900)
2024	90%	$589.17	8,578,700	-	-	(1,842,300)	(7,675,326)	6.68%	(5,833,000)	(2,123,500)	-	(1,220,200)	256,200	(963,900)	1,159,600	(33,955,900)
2025	90%	$609.79	8,879,000	-	-	(1,842,300)	(7,675,326)	6.18%	(5,833,000)	(1,964,500)	-	(760,900)	159,800	(601,100)	1,363,400	(33,109,300)
2026	90%	$631.14	9,189,700	-	-	(1,842,300)	(7,675,326)	5.71%	(5,833,000)	(1,816,900)	-	(302,500)	63,500	(239,000)	1,577,900	(32,218,600)
2027	90%	$653.23	9,511,400	-	-	(1,842,300)	(7,675,326)	5.29%	(5,833,000)	(1,680,800)	-	155,200	(32,600)	122,600	1,803,400	(31,293,200)
2028	90%	$676.09	9,844,300	-	-	(1,842,300)	(7,675,326)	4.89%	(5,833,000)	(1,554,600)	-	614,400	(129,000)	485,400	2,039,900	(30,341,600)
2029	90%	$699.75	10,188,800	-	-	(1,842,300)	(7,675,326)	4.52%	(5,833,000)	(1,438,200)	-	1,075,300	(225,800)	849,500	2,287,700	(29,371,400)
2030	90%	$724.24	10,545,400	-	-	(1,842,300)	(7,675,326)	4.46%	(5,833,000)	(1,419,100)	-	1,451,000	(304,700)	1,146,300	2,565,400	(28,382,300)
2031	90%	$749.59	10,914,500	-	-	(1,842,300)	(7,675,326)	4.46%	(5,833,000)	(1,418,800)	-	1,820,400	(382,300)	1,438,100	2,856,900	(27,381,000)
2032	90%	$775.83	11,296,500	-	-	(1,842,300)	(7,675,326)	4.46%	(5,833,000)	(1,419,100)	-	2,202,100	(462,400)	1,739,700	3,158,700	(26,374,500)
2033	90%	$802.98	11,691,900	-	-	(1,842,300)	(7,675,326)	4.46%	(5,833,000)	(1,418,800)	-	2,597,800	(545,500)	2,052,300	3,471,000	(25,369,100)
2034	90%	$831.09	12,101,100	-	-	(1,842,300)	(7,675,326)	4.46%	(5,833,000)	(1,419,100)	-	3,006,700	(631,400)	2,375,300	3,794,400	(24,369,900)
2035	90%	$860.18	12,524,600	-	-	(1,842,300)	(7,675,326)	4.46%	(5,833,000)	(1,418,800)	-	3,430,600	(720,400)	2,710,100	4,128,900	(23,381,500)
2036	90%	$890.28	12,963,000	-	1,155,500	(1,842,300)	(7,675,326)	4.46%	(5,833,000)	(1,419,100)	-	3,868,600	(812,400)	3,056,200	5,630,800	(22,156,100)



Profitability Measures

The Internal Rate of Return (IRR) for this project is -0.68%

The Net Present Value (NPV) of this project in 2020 is $ (22,156,100)

ROI Analysis (Third Production Year)

Annual Sales	**8,578,700**
Annual Costs	**(7,675,326)**
Depreciation	**(2,811,438)**
Income Tax	**400,693**
Net Earnings	**(1,507,371)**
Total Capital Investment	**36,298,499**
ROI	**-4.15%**

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	50%
y-axis	5%

						Total Permanent Investment					
		$17,571,489	$21,085,787	$24,600,085	$28,114,382	$31,628,680	***$35,142,978***	$38,657,276	$42,171,574	$45,685,871	$49,200,169
Product Price	$523	14.84%	9.92%	6.02%	2.82%	0.10%	-2.27%	-4.36%	-6.24%	-7.95%	-9.52%
	$528	15.34%	10.35%	6.42%	3.18%	0.44%	-1.94%	-4.04%	-5.92%	-7.64%	-9.21%
	$534	15.84%	10.78%	6.80%	3.53%	0.77%	-1.62%	-3.73%	-5.62%	-7.33%	-8.91%
	$539	16.33%	11.21%	7.18%	3.89%	1.10%	-1.30%	-3.42%	-5.32%	-7.04%	-8.62%
	$545	16.82%	11.63%	7.56%	4.23%	1.43%	-0.99%	-3.12%	-5.02%	-6.75%	-8.33%
	$550	17.31%	12.05%	7.93%	4.57%	1.75%	-0.68%	-2.82%	-4.73%	-6.46%	-8.05%
	$556	17.79%	12.46%	8.30%	4.91%	2.07%	-0.38%	-2.53%	-4.45%	-6.18%	-7.77%
	$561	18.27%	12.87%	8.66%	5.24%	2.38%	-0.09%	-2.25%	-4.17%	-5.91%	-7.50%
	$567	18.74%	13.27%	9.02%	5.57%	2.68%	0.21%	-1.97%	-3.90%	-5.64%	-7.24%
	$572	19.21%	13.67%	9.37%	5.90%	2.99%	0.49%	-1.69%	-3.63%	-5.38%	-6.98%
	$578	19.68%	14.07%	9.73%	6.22%	3.29%	0.78%	-1.42%	-3.37%	-5.12%	-6.72%

Process Title: ***Green Ammonia***
Product: ***Ammonia***
Plant Site Location: ***SW Norway***

Timeline:

Number of Years for Design	1	(must be whole number)
Number of Years for Construction	1	(must be whole number)
Number of Years for Production	15	
Total Number of Years for Project	17	
Start Year	2020	
Site Factor	1.00	

Continuous Operation:

Days per Year	350	
OR		
Hours per Year	0	
OR		
Operating Factor		(if multiple entries, "Operating Factor" is used)

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

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	20 year	

Income Tax Rate	21%	
Cost of Capital (for the NPV Calculation)	10%	(discount rate)
General Inflation Rate	0%	
Product Inflation Rate	0%	
Variable Cost Inflation Rate	0%	
Fixed Cost Inflation Rate	0%	

Product Information:

Enter Product Units (i.e. lb, gram, gal, etc)	*ton*	
Price Per Unit	$550.00	/ton
Number of units per:	(Specify ONE of the three. If multiple entries, "Year" is used.)	
Year	-	ton per Year
OR		
Day	-	ton per Day
OR		
Hour	2	ton per Hour

Raw Materials

	Raw Material:	Unit:	Required Ratio:		Cost of Raw Ma
1	Water	ton	1.5	ton per ton of Ammonia	$0.000E+00
2	Air	ton	1	ton per ton of Ammonia	$0.000E+00
3					
4					
5					
6					
7					
8					
9					
10					
	Total Weighted Average:				$0.000E+00

Byproducts

	Byproduct:	Unit:	Ratio to Product		Byproduct Selli
1	Oxygen	kg	220	kg per ton of Ammonia	$0.200
2					
3					
4					
5					
6					
7					
8					
9					
10					
	Total Weighted Average:				$44.000

Utilities

	Utility:	Unit:	Required Ratio		Utility Cost
1	High Pressure Steam	MT	0	MT per ton of Ammonia	
2	Low Pressure Steam	MT	0	MT per ton of Ammonia	
3	Process Water	gal	0	gal per ton of Ammonia	
4	Cooling Water	MT	17.34046236	MT per ton of Ammonia	$0.027
5	Chilled Water	MT	71.02379775	MT per ton of Ammonia	$1.500
6					
7					
8					
9					
10					
	Total Weighted Average:				$107.004

iscrete used by default)

terial:
per ton
per ton

per ton of Ammonia

ng Price
per kg

per ton of Ammonia

per MT
per MT
per gal
per MT
per MT

per ton of Ammonia

Selling Price Worksheet

This worksheet is optional. It may be used to adjust the product selling prices each year. Your inputs for the product prices, adjusted using the inflation rates, are entered as default values. To change, enter a price into the "Manual Input Price" column.

Year	Calculated Unit Price	Manual Input Price	Price to Be Used
2022	$550.00	$550.00	$550.00
2023	$550.00	$569.25	$569.25
2024	$550.00	$589.17	$589.17
2025	$550.00	$609.79	$609.79
2026	$550.00	$631.14	$631.14
2027	$550.00	$653.23	$653.23
2028	$550.00	$676.09	$676.09
2029	$550.00	$699.75	$699.75
2030	$550.00	$724.24	$724.24
2031	$550.00	$749.59	$749.59
2032	$550.00	$775.83	$775.83
2033	$550.00	$802.98	$802.98
2034	$550.00	$831.09	$831.09
2035	$550.00	$860.18	$860.18
2036	$550.00	$890.28	$890.28

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	⇨	**30**	**Days**
Cash Reserves (excluding Raw Materials)	⇨	**30**	**Days**
Accounts Payable	⇨	**30**	**Days**
Ammonia Inventory	⇨	**3**	**Days**
Raw Materials	⇨	**2**	**Days**

Total Permanent Investment

		% of Total Permanent Investment	
Year:	**2021**	100%	(default is first year of Construction, otherwis
	2022	0%	
	2023	0%	
	2024	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 Investme
Cost of Land:	0.50%	of Total Depreciable Capital
Cost of Royalties:	$0	
Cost of Plant Start-Up:	10.00%	of Total Depreciable Capital

Equipment Costs

Equipment Description	Type	Purchase Cost	Bare Module Factor	Bare Module Cost
Name	(must be filled-in!)		(default 3.21 if blank)	
Haber Bosch Reactor	Process Machinery	$81,929	4.16	$340,823
Sodium Doped Iron Catalyst	Catalysts	$20,000	1.00	$20,000
HB-CP-01	Process Machinery	$14,021	2.15	$30,146
HB-CP-02	Process Machinery	$1,405,174	2.15	$3,021,123
HB-HXA-01	Process Machinery	$40,114	3.17	$127,161
HB-HXA-02	Process Machinery	$33,407	3.17	$105,901
HB-HXA-03	Process Machinery	$48,292	3.17	$153,087
HB-HXA-04	Process Machinery	$37,992	3.17	$120,435
HB-S-01	Process Machinery	$15,871	4.16	$66,024
HB-S-02	Process Machinery	$13,735	4.16	$57,136
Storage Tank	Storage	$235,000	4.00	$940,000
SOEC	Process Machinery	$7,500,000	2.00	$15,000,000
UP-EM-01	Process Machinery	$1,733	3.30	$5,720
UP-PM-01	Process Machinery	$12,748	3.30	$42,068
UP-CP-01	Process Machinery	$223,248	2.15	$479,984
UP-CP-02	Process Machinery	$244,570	2.15	$525,826
UP-CP-03	Process Machinery	$234,696	2.15	$504,596
UP-CP-04	Process Machinery	$25,785	2.15	$55,437
UP-HX-01	Process Machinery	$34,228	3.17	$108,504
UP-HX-02	Process Machinery	$46,708	3.17	$148,064
UP-CO-01	Process Machinery	$14,337	3.17	$45,449
UP-CO-02	Process Machinery	$12,328	3.17	$39,081
UP-CO-03	Process Machinery	$14,564	3.17	$46,168
UP-CD-01	Process Machinery	$47,353	3.17	$150,110
UP-BO-01	Process Machinery	$891,249	2.19	$1,951,834
UP-FH-01	Process Machinery	$49,920	2.19	$109,325
M6 Filter	Process Machinery	$4,000	2.00	$8,000
Ion Exchange Unit	Process Machinery	$150,000	2.00	$300,000
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0
				$0

Fixed Costs

Operations

Operators per Shift:	5	(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:	$7,920.00	per year, for each Operator per Shift		
Control Laboratory:	$11,700.00	per year, for each Operator per Shift		

Maintenance

Wages and Benefits:	2.00%	of Total Depreciable Capital
Salaries and Benefits:	25.00%	of Maintenance Wages and Benefits
Materials and Services:	100.00%	of Maintenance Wages and Benefits
Maintenance Overhead:	5.00%	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:	2.00%	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):	$0
Licensing Fees:	$0
Miscellaneous:	$0

Depletion Allowance

Annual Depletion Allowance:	$0

Appendix E.1: Equipment Costing SOEC

Bare Module Cost Analysis Worksheet

Instructions (Read Carefully Before Using!!!)

1. Input the CE cost index below that corresponds to the date when you want the cost estimate (e.g. a 2018 CE will provide 2018 costs for equipment) . The CE index will automatically update each page accordingly.
2. Select the link below for the appropriate unit operation. Links provided at the top of each worksheet will return back to this title page.
3. Enter all data into the yellow boxes ONLY. For a process involving multiple sizes of the same type unit operations, use a different line to input the specs (up to 5 provided)

Input

4. The Bare Module Cost of the Unit Operation is calculated and shown in red.

Bare Module Cost

5. If you are extrapolating the cost correlations, the spreadsheet will warn you. Consult the textbook for valid ranges of the equations, and use outside those ranges very carefully.
6. Below are the individual unit bare module costs and compiled tables of each type of unit operation, summarizing the different properties.
7. Total Bare Module Cost for all types of all equipment is also displayed below.

All costing from:
Product and Process Design Principles
4th Edition © Seider, Lewin, Seader, Widagdo, Gani, Ng, 2017
Worksheet prepared by Prof. Russell Dunn, Department of Chemical and Biomolecular Engineering, Vanderbilt University
Revised by Prof. Bruce Vrana, Department of Chemical and Biomolecular Engineering, University of Pennsylvania

CE Cost Index for this Estimate 600

Total Bare module Cost= **$ 4,062,057**

Equipment	**Total Cbm For each Unit Op**	
Electric Motors	$ 5,720	
Centrifugal Pumps	$ 42,068	
External Gear Pumps	$ -	
Reciprocating Plunger Pumps	$ -	
Fans	$ -	
Centrifugal (turbo) Blower	$ -	
Rotary Straight Lobe Blower	$ -	
Compressors	$ 1,565,844	Warning - extrapolation in cost estimate, refer to textbook for valid range
Shell and Tube Heat Exchanger	$ 387,265	Warning - extrapolation in cost estimate, refer to textbook for valid range
Double Pipe Heat Exchanger	$ -	
Fired Heaters	$ 2,061,159	Warning - extrapolation in cost estimate, refer to textbook for valid range
Pressure Vessel	$ -	
Packed Column	$ -	
Tray Column	$ -	
Storage Tanks	$ -	

Electric Motors	Q (gal/min)	H (ft)	FT	Pb (hp)	Cbm
UP-EM-01	40.58	1357.6	1.00	33.52	5720
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0

Centrifugal Pumps	Q (gal/min)	H (ft)	Ft	Fm	Cbm
UP-PM-01	40.58	1357.6	2.7	1	42068
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0

External Gear Pumps	Q (gal/min)	Fm	Cbm
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0

Reciprocating Plunger Pumps	Q (gal/min)	H (ft)	Fm	Pb (hp)	Cbm
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0

Fans	Type of Fan	Q (ACFM)	CBM
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0

Centrifugal Blower	Qi (cuft/min)	Pi (lbf/in2)	Po (lbf/in2)	Pc	Cbm
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0

Rotary Straight-Lobe Blowers	Qi (ft^3/min)	Pi (lbf/in^2)	Po(lbf/in^2)	Pc (hp)	Cbm
	0	*0*	*0*	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0

Compressor	Type	Pc (hp)	CBM	
UP-CP-01	Centrifugal Compressor	138	479984	Warning - extrapolation in cost estimate, refer to textbook for valid range
UP-CP-02	Centrifugal Compressor	159.5	525826	Warning - extrapolation in cost estimate, refer to textbook for valid range
UP-CP-03	Centrifugal Compressor	149.4	504596	Warning - extrapolation in cost estimate, refer to textbook for valid range
UP-CP-04	Centrifugal Compressor	2.63	55437	Warning - extrapolation in cost estimate, refer to textbook for valid range

	0	0	0

Shell and Tube Heat Exchangers	Heat Exchanger Design	Surface Area (f	Pressure (psig)	CBM	
UP-HX-01	Fixed Head	75.97	561.15	108504	Warning - extrapolation in cost estimate, refer to textbook for valid range
UP-HX-02	Fixed Head	13.9326	555.35	148064	Warning - extrapolation in cost estimate, refer to textbook for valid range
UP-CO-01	Fixed Head	21.6	30.16	45449	Warning - extrapolation in cost estimate, refer to textbook for valid range
UP-CO-02	Fixed Head	40.9	150.22	39081	Warning - extrapolation in cost estimate, refer to textbook for valid range
UP-CO-03	Fixed Head	31.7	549.55	46168	Warning - extrapolation in cost estimate, refer to textbook for valid range

Double Pipe Heat Exchanger	Surface Area (ft^2)	Pressure (psig)	CBM
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0

Fired Heaters	Q (BTU/hr)	Pressure (psig)	Fm	Cbm	
UP-BO-01	2.78E+07	565.5	1.4	1951834	
UP-FH-01	7.07E+05	565.5	1.4	109325	Warning - extrapolation in cost estimate, refer to textbook for valid range
	0.00E+00	0	0	0	
	0.00E+00	0	0	0	
	0.00E+00	0	0	0	

Pressure vessel	Type	Di	L	Pressure	Weight	Cbm
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0

Packed Column	Di (ft)	L (ft)	Pressure (psig)	Vp (ft^3)	Cbm
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0

Tray Column	Di (ft)	L(ft)	Pressure (psig)	Nt	Ftt	Cbm
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0

Storage Tanks	V (gal)	Cbm
	0	0
	0	0
	0	0
	0	0
	0	0

Electric Motors

S

FBM 3.3 CE = 600

Given Q, H, ρ

Name	Q	H	ρ	ηp	PB	ηm	Pc
	(gal/min)	*(ft)*	*(lb/gal)*		*(hp)*		*(hp)*
UP-EM-01	40.58	1357.6	8.21	0.41	33.52	0.89	37.68

Summary page

CB	FT	CP	CP	CBM
$ (CE=567)	*Table 22.22*	*$ (CE=567)*	*$ (Given CE)*	*$ (Given CE)*
1638	1.00	1638	1733	**5720**

Centrifugal Pumps

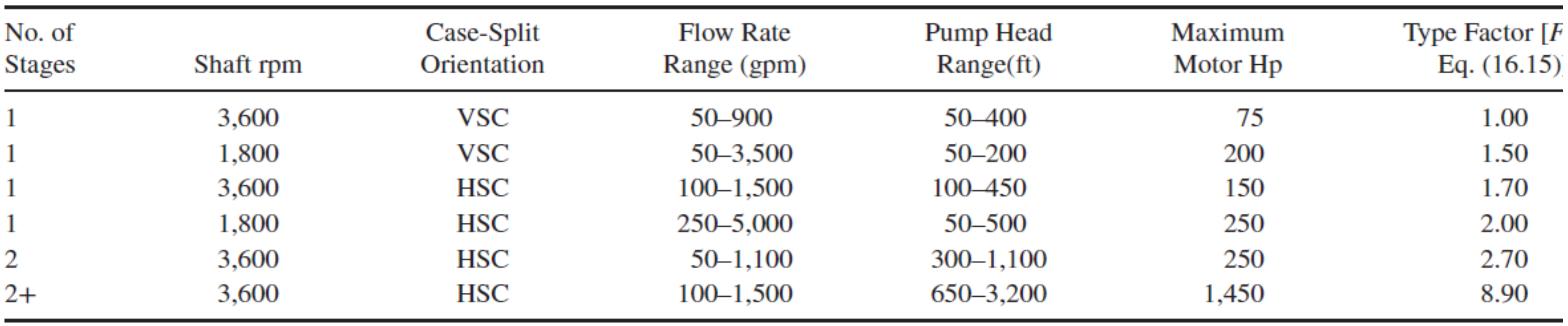
Summary page

FBM = 3.3

CE = 600

Name	Q *(gal/min)*	H *(ft)*	S *(gpm)(ft)^.5*	CB *$ (CE=567)*	FT *Table 22.20*	FM *Table 22.21*	CP *$ (CE=567)*	CP *$ (Given CE)*	CBM *$ (Given CE)*
UP-PM-01	40.58	1357.6	1495	4462	2.7	1	12047	12748	**42068**
			0	0			0	0	**0**
			0	0			0	0	**0**
			0	0			0	0	**0**
			0	0			0	0	**0**

Table 16.20 Typical Types of Radial Centrifugal Pumps and F_T Factors



No. of Stages	Shaft rpm	Case-Split Orientation	Flow Rate Range (gpm)	Pump Head Range(ft)	Maximum Motor Hp	Type Factor [F Eq. (16.15)
1	3,600	VSC	50–900	50–400	75	1.00
1	1,800	VSC	50–3,500	50–200	200	1.50
1	3,600	HSC	100–1,500	100–450	150	1.70
1	1,800	HSC	250–5,000	50–500	250	2.00
2	3,600	HSC	50–1,100	300–1,100	250	2.70
2+	3,600	HSC	100–1,500	650–3,200	1,450	8.90

Table 16.21 Materials of Construction Factors, F_M, for Centrifugal Pumps

Material of Construction	Material Factor [F_{M}, in Eq. (16.15)]
Cast iron	1.00
Ductile iron	1.15
Cast steel	1.35
Bronze	1.90
Stainless steel	2.00
Hastelloy C	2.95
Monel	3.30
Nickel	3.50
Titanium	9.70

Compressors

FBM = 2.15

CE = 600

Name	Compressor Type	Aspen Pc	Cb	FD	FM	Cp	Cp
	(screw, centrifugal, reciprocating)	*hp*	*$(CE=567)*	*see below*	*see below*	$ (CE=567)	*$ (Given CE)*
UP-CP-01	Centrifugal Compressor	138	210970	1	1	210970	223248
UP-CP-02	Centrifugal Compressor	159.5	231119	1	1	231119	244570
UP-CP-03	Centrifugal Compressor	149.4	221788	1	1	221788	234696
UP-CP-04	Centrifugal Compressor	2.63	17405	1	1.4	24367	25785
			0			0	0

Possible FD values

Electric	1
Steam	1.15
Gas	1.25

Possible FM values

Cast iron	1
Carbon Steel	1
Stainless Steel	2.5
Nickel Alloy	5

Summary page

CBM *$ (Given CE)*	
479984	Warning - extrapolation in cost estimate, refer to textbook for valid range
525826	Warning - extrapolation in cost estimate, refer to textbook for valid range
504596	Warning - extrapolation in cost estimate, refer to textbook for valid range
55437	Warning - extrapolation in cost estimate, refer to textbook for valid range
0	

Tube Heat Exchangers

Summary pag

FBM = 3.17

CE = 600

Name	Heat Exchanger Design	Surface Area ft^2	CB $ (CE=567)	a Table 22.25	b Table 22.25	FM	Pressure psig	Fp
UP-HX-01	Fixed Head	75.97	10632	1.7	0.07	2.68094566	561.15	1.13483818
UP-HX-02	Fixed Head	13.9326	15866	1.55	0.05	2.45615316	555.35	1.13269332
UP-CO-01	Fixed Head	21.6	13549	0	0	1	30.16	1
UP-CO-02	Fixed Head	40.9	11522	0	0	1	150.22	1.01117583
UP-CO-03	Fixed Head	31.7	12174	0	0	1	549.55	1.13055988

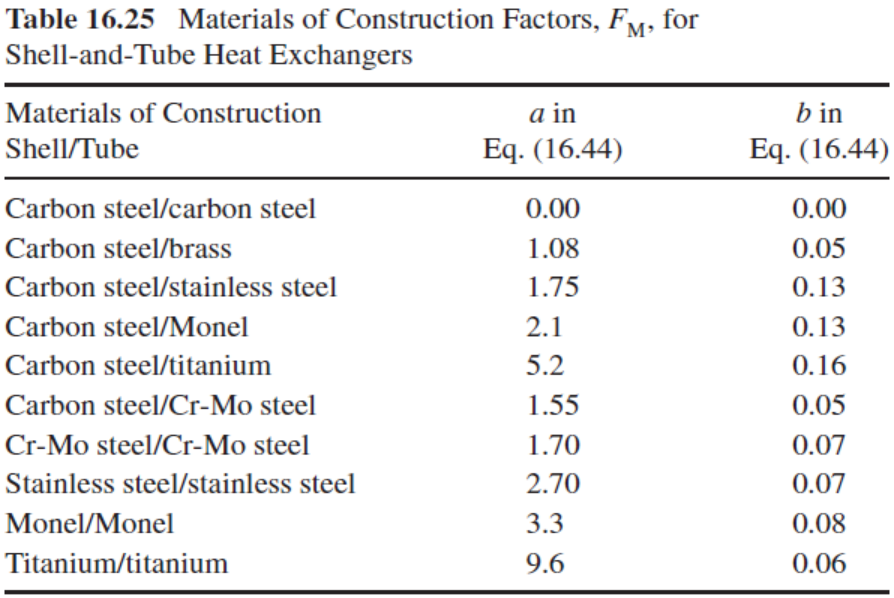


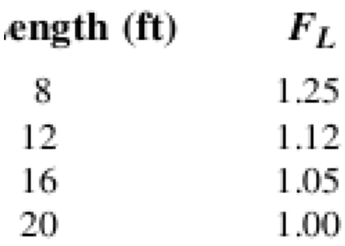
Table 16.25 Materials of Construction Factors, F_M, for Shell-and-Tube Heat Exchangers

Materials of Construction Shell/Tube	*a* in Eq. (16.44)	*b* in Eq. (16.44)
Carbon steel/carbon steel	0.00	0.00
Carbon steel/brass	1.08	0.05
Carbon steel/stainless steel	1.75	0.13
Carbon steel/Monel	2.1	0.13
Carbon steel/titanium	5.2	0.16
Carbon steel/Cr-Mo steel	1.55	0.05
Cr-Mo steel/Cr-Mo steel	1.70	0.07
Stainless steel/stainless steel	2.70	0.07
Monel/Monel	3.3	0.08
Titanium/titanium	9.6	0.06

Tube L

e

FL *See below*	Cp *$ (CE=567)*	Cp *$(Given CE)*	CBM *$ (Given CE)*	
1	32346	34228	**108504**	Warning - extrapolation in cost estimate, refer to textbook for valid range
1	44139	46708	**148064**	Warning - extrapolation in cost estimate, refer to textbook for valid range
1	13549	14337	**45449**	Warning - extrapolation in cost estimate, refer to textbook for valid range
1	11650	12328	**39081**	Warning - extrapolation in cost estimate, refer to textbook for valid range
1	13763	14564	**46168**	Warning - extrapolation in cost estimate, refer to textbook for valid range



ength (ft)	F_L
8	1.25
12	1.12
16	1.05
20	1.00

Tube Heat Exchangers

Summary page

FBM = 3.17

CE = 600

Name	Heat Exchanger Design	Surface Area	CB	a	b	FM	Pressure	Fp
		ft^2	*$ (CE=567)*	*Table 22.25*	*Table 22.25*		*psig*	
UP-CD-01	Fixed Head	710	14920	1.55	0.05	2.65296801	549.55	1.13055988
			0			0		1
			0			0		1
			0			0		1
			0			0		1

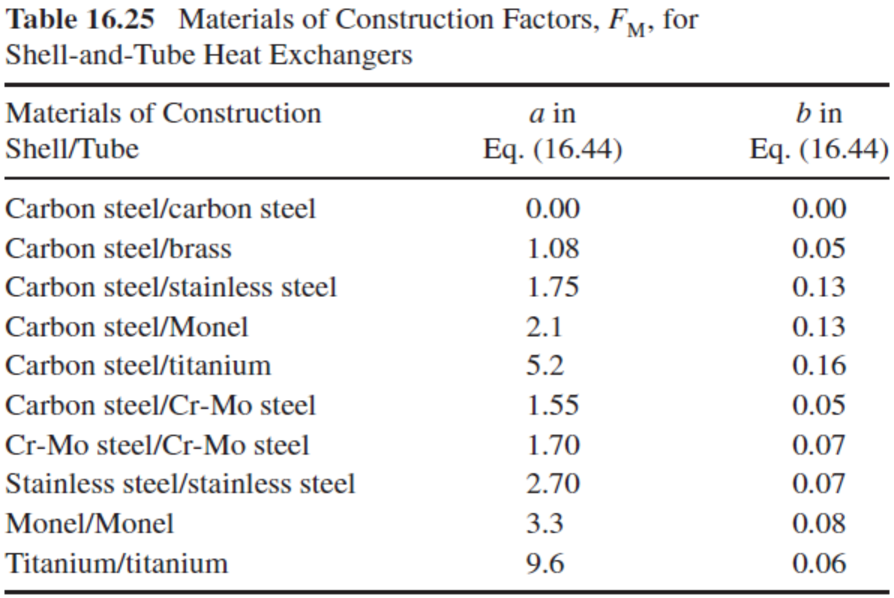


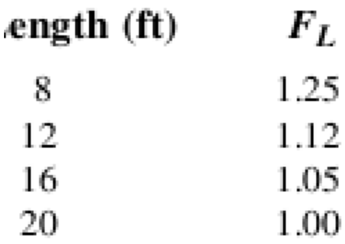
Table 16.25 Materials of Construction Factors, F_M, for Shell-and-Tube Heat Exchangers

Materials of Construction Shell/Tube	*a* in Eq. (16.44)	*b* in Eq. (16.44)
Carbon steel/carbon steel	0.00	0.00
Carbon steel/brass	1.08	0.05
Carbon steel/stainless steel	1.75	0.13
Carbon steel/Monel	2.1	0.13
Carbon steel/titanium	5.2	0.16
Carbon steel/Cr-Mo steel	1.55	0.05
Cr-Mo steel/Cr-Mo steel	1.70	0.07
Stainless steel/stainless steel	2.70	0.07
Monel/Monel	3.3	0.08
Titanium/titanium	9.6	0.06

Tube L

e

FL	Cp	Cp	CBM
See below	$ (CE=567)	$(Given CE)	$ (Given CE)
1	44749	47353	**150110**
	0	0	**0**
	0	0	**0**
	0	0	**0**
	0	0	**0**



ength (ft)	F_L
8	1.25
12	1.12
16	1.05
20	1.00

Fired Heaters

Summary page

FBM = 2.19
see below

CE = 600

Name	Q *BTU/hr*	P *psig*	CB *$ (CE=567)*	FM *see below*	Fp	CP *$ (CE=567)*	CP *$ (Given CE)*	CBM *$ (Given CE)*
UP-BO-01	2.78E+07	565.5	598941	1.4	1.00442682	842230	891249	**1951834**
UP-FH-01	7.07E+05	565.5	33547	1.4	1.00442682	47174	49920	**109325**
			0		1	0	0	**0**
			0		1	0	0	**0**
			0		1	0	0	**0**

Possible FBM Values

2.19	shop fabricated
1.86	field fabricated

Possible FM Values

1.4	Cr-Mo alloy steel
1.7	stainless steel

Appendix E.2: Equipment Costing Haber Bosch

Bare Module Cost Analysis Worksheet

Instructions (Read Carefully Before Using!!!)

1. Input the CE cost index below that corresponds to the date when you want the cost estimate (e.g. a 2018 CE will provide 2018 costs for equipment) . The CE index will automatically update each page accordingly.
2. Select the link below for the appropriate unit operation. Links provided at the top of each worksheet will return back to this title page.
3. Enter all data into the yellow boxes ONLY. For a process involving multiple sizes of the same type unit operations, use a different line to input the specs (up to 5 provided)

Input

4. The Bare Module Cost of the Unit Operation is calculated and shown in red.

Bare Module Cost

5. If you are extrapolating the cost correlations, the spreadsheet will warn you. Consult the textbook for valid ranges of the equations, and use outside those ranges very carefully.
6. Below are the individual unit bare module costs and compiled tables of each type of unit operation, summarizing the different properties.
7. Total Bare Module Cost for all types of all equipment is also displayed below.

All costing from:
Product and Process Design Principles
4th Edition **© Seider, Lewin, Seader, Widagdo, Gani, Ng, 2017**
Worksheet prepared by Prof. Russell Dunn, Department of Chemical and Biomolecular Engineering, Vanderbilt University
Revised by Prof. Bruce Vrana, Department of Chemical and Biomolecular Engineering, University of Pennsylvania

CE Cost Index for this Estimate 600

Total Bare module Cost= **$ 4,021,836**

Equipment	**Total Cbm For each Unit Op**	
Electric Motors	$ -	
Centrifugal Pumps	$ -	
External Gear Pumps	$ -	
Reciprocating Plunger Pumps	$ -	
Fans	$ -	
Centrifugal (turbo) Blower	$ -	
Rotary Straight Lobe Blower	$ -	
Compressors	$ 3,051,269	Warning - extrapolation in cost estimate, refer to textbook for valid range
Shell and Tube Heat Exchanger	$ 506,584	Warning - extrapolation in cost estimate, refer to textbook for valid range
Double Pipe Heat Exchanger	$ -	
Fired Heaters	$ -	
Pressure Vessel	$ 463,983	Warning - extrapolation in cost estimate, refer to textbook for valid range
Packed Column	$ -	
Tray Column	$ -	
Storage Tanks	$ -	

Electric Motors	Q (gal/min)	H (ft)	FT	Pb (hp)	Cbm
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0

Centrifugal Pumps	Q (gal/min)	H (ft)	Ft	Fm	Cbm
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0

External Gear Pumps	Q (gal/min)	Fm	Cbm
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0

Reciprocating Plunger Pumps	Q (gal/min)	H (ft)	Fm	Pb (hp)	Cbm
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0
	0	0	0.00	0.00	0

Fans	Type of Fan	Q (ACFM)	CBM
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0

Centrifugal Blower	Qi (cuft/min)	Pi (lbf/in2)	Po (lbf/in2)	Pc	Cbm
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0

Rotary Straight-Lobe Blowers	Qi (ft^3/min)	Pi (lbf/in^2)	Po(lbf/in^2)	Pc (hp)	Cbm
	0	*0*	*0*	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0
	0	0	0	0.00	0

Compressor	Type	Pc (hp)	CBM	
	0	0	0	
HB-CP-01	Centrifugal Compressor	1	30146	Warning - extrapolation in cost estimate, refer to textbook for valid range
HB-CP-02	Centrifugal Compressor	1500	3021123	
	0	0	0	

	0	0	0

Shell and Tube Heat Exchangers	Heat Exchanger Design	Surface Area (f	Pressure (psig)	CBM	
HB-HXA-02	Fixed Head	79	490	105901	Warning - extrapolation in cost estimate, refer to textbook for valid range
HB-HXA-01	Fixed Head	24	490	127161	Warning - extrapolation in cost estimate, refer to textbook for valid range
	0	0	0	0	
HB-HXA-04	Fixed Head	25	507.5	120435	Warning - extrapolation in cost estimate, refer to textbook for valid range
HB-HXA-03	Fixed Head	25	1160	153087	Warning - extrapolation in cost estimate, refer to textbook for valid range

Double Pipe Heat Exchanger	Surface Area (ft^2)	Pressure (psig)	CBM
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	0	0	0

Fired Heaters	Q (BTU/hr)	Pressure (psig)	Fm	Cbm
	0.00E+00	0	0	0
	0.00E+00	0	0	0
	0.00E+00	0	0	0
	0.00E+00	0	0	0
	0.00E+00	0	0	0

Pressure vessel	Type	Di	L	Pressure	Weight	Cbm	
HB-S-01	Vertical	0.87	10.37	565.5	479.7687074	66024	Warning - extrapolation in cost estimate, refer to textbook for valid range
HB-S-02	Vertical	0.78	12.16	145	328.3323075	57136	Warning - extrapolation in cost estimate, refer to textbook for valid range
	0	0	0	0	0	0	
Haber Bosch Reactor	Vertical	2.87	14.35	1160	11269.89793	340823	
	0	0	0	0	0	0	

Packed Column	Di (ft)	L (ft)	Pressure (psig)	Vp (ft^3)	Cbm
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0

Tray Column	Di (ft)	L(ft)	Pressure (psig)	Nt	Ftt	Cbm
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0
	0	0	0	0	0	0

Storage Tanks	V (gal)	Cbm
	0	0
	0	0
	0	0
	0	0
	0	0

Compressors

FBM = 2.15 CE = 600

Name	Compressor Type	Pc	Cb	FD	FM	Cp	Cp
	(screw, centrifugal, reciprocating)	*hp*	*$(CE=567)*	*see below*	*see below*	$ (CE=567)	*$ (Given CE)*
			0	1	1.4	0	0
HB-CP-01	Centrifugal Compressor	1	9464	1	1.4	13250	14021
HB-CP-02	Centrifugal Compressor	1500	948492	1	1.4	1327889	1405174
			0			0	0
			0			0	0

Possible FD values	
Electric	1
Steam	1.15
Gas	1.25

Possible FM values	
Cast iron	1
Carbon Steel	1
Stainless Steel	2.5
Nickel Alloy	5

Summary page

CBM *$ (Given CE)*	
0	
30146	Warning - extrapolation in cost estimate, refer to textbook for valid range
3021123	
0	
0	

Tube Heat Exchangers

Summary pag

FBM = 3.17 CE = 600

Name	Heat Exchanger Design	Surface Area *ft^2*	CB *$ (CE=567)*	a *Table 22.25*	b *Table 22.25*	FM	Pressure *psig*	Fp
HB-HXA-02	Fixed Head	79	10605	1.7	0.07	2.68363483	490	1.109317
HB-HXA-01	Fixed Head	24	13118	1.7	0.07	2.60492959	490	1.109317
			0			0		1
HB-HXA-04	Fixed Head	25	12963	1.55	0.05	2.48303299	507.5	1.11543456
HB-HXA-03	Fixed Head	25	12963	1.55	0.05	2.48303299	1160	1.417852

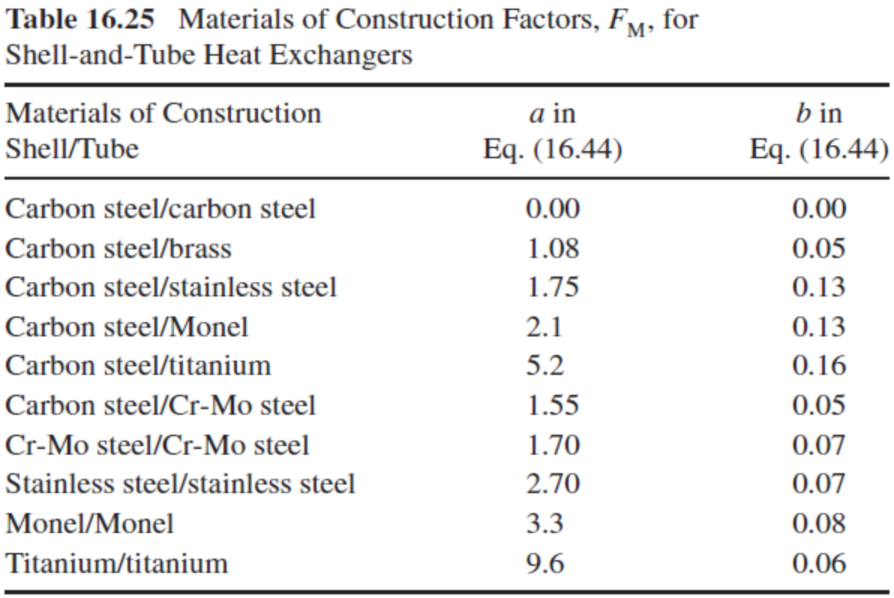


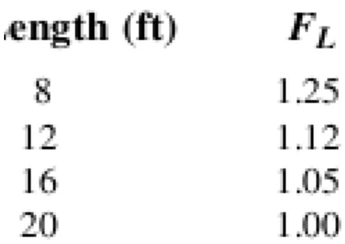
Table 16.25 Materials of Construction Factors, F_M, for Shell-and-Tube Heat Exchangers

Materials of Construction Shell/Tube	*a* in Eq. (16.44)	*b* in Eq. (16.44)
Carbon steel/carbon steel	0.00	0.00
Carbon steel/brass	1.08	0.05
Carbon steel/stainless steel	1.75	0.13
Carbon steel/Monel	2.1	0.13
Carbon steel/titanium	5.2	0.16
Carbon steel/Cr-Mo steel	1.55	0.05
Cr-Mo steel/Cr-Mo steel	1.70	0.07
Stainless steel/stainless steel	2.70	0.07
Monel/Monel	3.3	0.08
Titanium/titanium	9.6	0.06

Tube L

e

FL *See below*	Cp *$ (CE=567)*	Cp *$(Given CE)*	CBM *$ (Given CE)*	
1	31570	33407	**105901**	Warning - extrapolation in cost estimate, refer to textbook for valid range
1	37908	40114	**127161**	Warning - extrapolation in cost estimate, refer to textbook for valid range
1	0	0	**0**	
1	35902	37992	**120435**	Warning - extrapolation in cost estimate, refer to textbook for valid range
1	45636	48292	**153087**	Warning - extrapolation in cost estimate, refer to textbook for valid range



ength (ft)	F_L
8	1.25
12	1.12
16	1.05
20	1.00

Pressure Vessels

FBM = 4.16 CE = 600

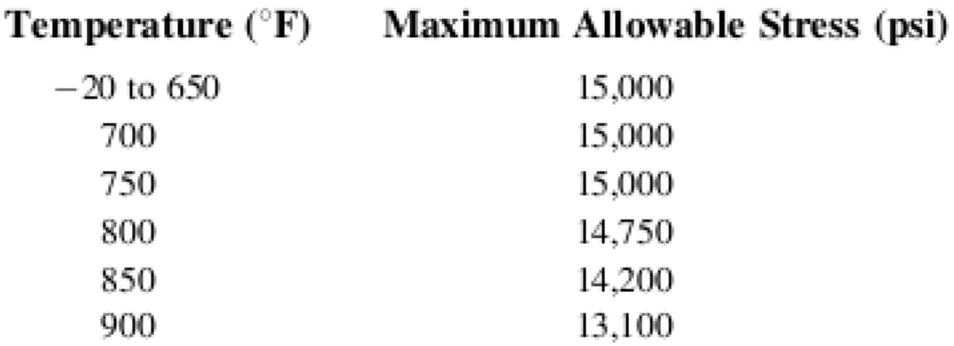
Name	Type	Di	L	Pressure	Pd	E
		ft	*ft*	*psig*	*psig*	
HB-S-01	Vertical	0.87	10.37	565.5	649	1
HB-S-02	Vertical	0.78	12.16	145	182	1
					0	
Haber Bosch Reactor	Vertical	2.87	14.35	1160	1272	1
					0	

Note: see text for vacuum vessels

Note: if carbon steel, S = 13750

For 304 Stainless, S = 11200

Potential Values for S (low alloy steel):



Temperature (°F)	Maximum Allowable Stress (psi)
−20 to 650	15,000
700	15,000
750	15,000
800	14,750
850	14,200
900	13,100

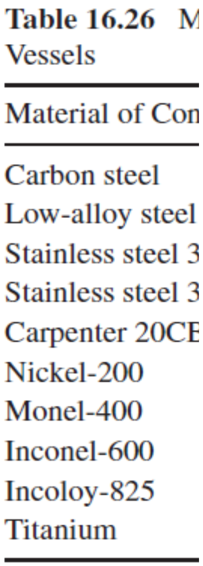


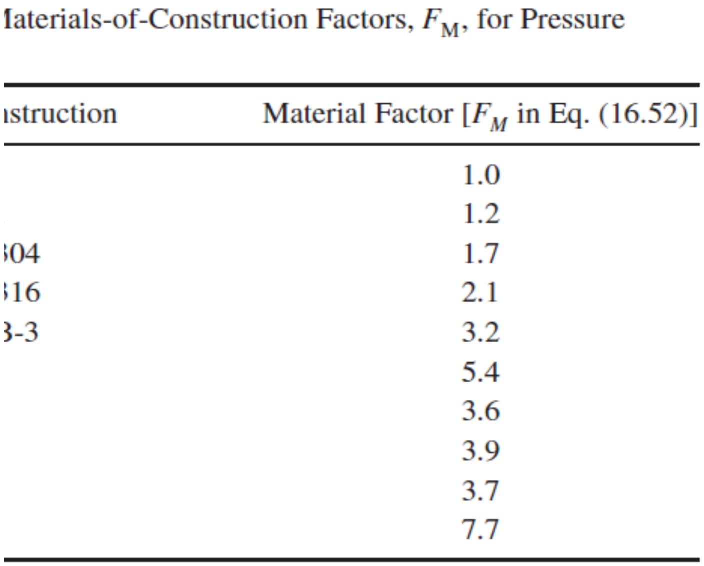
Table 16.26 M

Vessels

Material of Con
Carbon steel
Low-alloy steel
Stainless steel 3
Stainless steel 3
Carpenter 20CE
Nickel-200
Monel-400
Inconel-600
Incoloy-825
Titanium

Summary page

S	tp	Wind/Earthquake?	tw	taverage	Corrosion tc	ts	tsrounded
psi (see below)	*ft*	*Include=Y*	*ft*	*ft*	*inch*	*inch*	*inch*
15000	0.01932	N	0.00000	0.01932	0.125	0.35683	0.37500
15000	0.00477	N	0.00000	0.00477	0.125	0.18222	0.25000
	0.00000		0.00000	0.00000	0.125	0.12500	0.25000
15000	0.12824	N	0.00000	0.12824	0.125	1.66385	1.75000
	0.00000		0.00000	0.00000	0.125	0.12500	0.25000



aterials-of-Construction Factors, F_M, for Pressure

struction	Material Factor [F_M in Eq. (16.52)]
	1.0
	1.2
04	1.7
16	2.1
-3	3.2
	5.4
	3.6
	3.9
	3.7
	7.7

tsrounded *ft*	Density *lb/ft^3*	Weight *lb*	Cv *$ (CE=567)*	Cpl *$ (CE=567)*	Fm *Table 22.26*	Cp *$(CE=567)*	CP *$ (Given CE)*	Cbm *$ (Given CE)*	
0.0313	490	480	9333	1932	1.4	14998	15871	**66024**	Warning - extrapolation in
0.0208	490	328	7846	1994	1.4	12979	13735	**57136**	Warning - extrapolation in
0.0208	490	0	0	0	1.4	0	0	**0**	
0.1458	490	11270	51105	5875	1.4	77423	81929	**340823**	
0.0208	490	0	0	0	1	0	0	**0**	