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Mixed Plastics Waste to Ethylene and Propylene Feedstocks

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Abstract
Circular recycle of waste plastic holds significant environmental benefit in reducing the need for crude oil feed to produce plastic monomers and in addressing massive global accumulation of plastic waste. A two-stage cracking process is here explored for the reduction of long-chain polyethylene (PE), polypropylene (PP), and polystyrene (PS) to ethylene and propylene. The reaction yields useful byproducts, such as liquid fuel used to sustain the high energy demands of the process, and pressurized steam. A feed of 70 MT/day of PE, PP, and PS is assumed to be treated first in a rotary kiln pyrolysis reactor and secondly in a steam-cracking unit for the formation of short-chain unsaturated hydrocarbons. 41% of the feedstock by weight is converted to either ethylene or propylene. Due to the random nature of cracking, a pilot plant is deemed necessary to better understand this conversion. Heat integration is explored extensively throughout the cracking to employ other process products as fuel sources. A novel separation train and refrigeration cycle are then designed to isolate the two products of interest. The process is found not to be profitable, with an Internal Rate of Return of -4.74%, Net Present Value of -$18.8MM, and Return on Investment (ROI) in the third year of operation of -2.12%. However, a circular monomers facility holds significant value environmentally, and options are thus explored to potentially reduce the cost or make the process profitable.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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April 21, 2020

Dear Professor Bruce Vrana and Dr. Sean Holleran,

The enclosed report contains a process design for converting consumer and industrial waste plastic into ethylene and propylene monomers. The process is fed 68.9 imperial tons of a mix of low-density polyethylene, high-density polyethylene, polypropylene, and polystyrene. We initially aimed to follow a patent issued to Plastics Energy, but eventually decided to follow another pathway. In our design, the plastics are washed, dried, extruded, and are then pyrolyzed in two successive rotary kilns. Light gas product is then cracked in a steam cracker and is rapidly quenched to prevent further reactions. The resulting stream is then compressed and finally separated to in order to recover ethylene and propylene.

The plant is designed to be built in Borneo, Indonesia. It is designed to operate on a continuous basis for 24 hours per day, 350 days per year, for fifteen years of total operation. The plant is comprised of five distinct process sections: upstream processing; pyrolysis; steam cracking, quenching, and compression; separations; and a refrigeration system. Ethylene is produced at a rate of 1410 lbs/hr, and a purity of 99.0% by mass, qualifying it to be sold as polymer grade ethylene. Propylene is produced at a rate of 1250 lbs/hr, and a purity of 95.7% by mass, qualifying it to be sold as chemical grade propylene. Each product is sold for $0.69/lb.

From an economic standpoint, this process is not profitable. The plant requires a total capital investment of $27.5 MM dollars to achieve the desired conversion of 68.9 tons of plastic waste per day. The Internal Rate of Return (IRR) is -4.47%. While we do not recommend investing in this particular process, we believe that the chemical recycling of plastic waste is a worthy area of research and development, and we offer some modifications and alternatives to our proposed process that may result in a profitable process.

Thank you for your guidance throughout this project.

Sincerely,

Promise Adebayo-Ige	Sarah Engelhardt	Matthew Larson

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Mixed Plastics Waste to Ethylene and Propylene Feedstocks

Promise Adebayo-Ige | Sarah Engelhardt | Matthew Larson

Project submitted to Dr. Sean Patrick Holleran and Prof. Bruce Vrana
Project proposed by Stephen Tieri

Department of Chemical and Biomolecular Engineering
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April 21, 2020

Table of Contents

Section 1. Abstract

Circular recycle of waste plastic holds significant environmental benefit in reducing the need for crude oil feed to produce plastic monomers and in addressing massive global accumulation of plastic waste. A two-stage cracking process is here explored for the reduction of long-chain polyethylene (PE), polypropylene (PP), and polystyrene (PS) to ethylene and propylene. The reaction yields useful byproducts, such as liquid fuel used to sustain the high energy demands of the process, and pressurized steam. A feed of 70 MT/day of PE, PP, and PS is assumed to be treated first in a rotary kiln pyrolysis reactor and secondly in a steam-cracking unit for the formation of short-chain unsaturated hydrocarbons. 41% of the feedstock by weight is converted to either ethylene or propylene. Due to the random nature of cracking, a pilot plant is deemed necessary to better understand this conversion. Heat integration is explored extensively throughout the cracking to employ other process products as fuel sources. A novel separation train and refrigeration cycle are then designed to isolate the two products of interest. The process is found not to be profitable, with an Internal Rate of Return of -4.74%, Net Present Value of -$18.8MM, and Return on Investment (ROI) in the third year of operation of -2.12%. However, a circular monomers facility holds significant value environmentally, and options are thus explored to potentially reduce the cost or make the process profitable.

Section 2. Introduction and Objective-Time Chart

Plastic has become an essential part of life for people across the globe. With a diverse set of properties that allow it to perform myriad functions, it has become an indispensable material in a number of industries, from medicine to consumer-packaged goods. Unfortunately, with the surge of plastic use over the past few decades, plastic waste has become a huge threat to the environment. It is therefore imperative that a safe, effective, sustainable solution is developed to handle the world's plastic waste.

More than eight million metric tons of plastic waste are dumped into the ocean every year, which can harm marine organisms [2.1]. Plastic waste is equally harmful in an above-water setting. Only a small percent of plastic waste makes it to a recycling bin, let alone to a recycling plant. Countries like China that are equipped with recycling plants have stopped accepting plastic waste, and countries such as Malaysia, Vietnam, and Thailand have become the primary collectors, despite their waste management systems already nearing capacity [2.2]. Burdened with an overwhelming amount of plastic waste, these countries turn to dangerous methods of disposal, including dumping and incinerating waste near residents who are then harmed by these toxic fumes.

Currently, recycling is the most sustainable option for plastic waste disposal, although it is estimated that less than 10% of plastic globally gets recycled [2.3]. There are two main recycling processes for plastic waste: mechanical recycling and chemical recycling. In mechanical recycling, plastic goods are broken down mechanically (i.e. through cutting or shredding) and turned into new products. The chemical structure of the plastic material stays the same, but the function of the material itself changes; for example, polyethylene terephthalate, or PET, which is the material that most plastic bottles are made from, can be mechanically recycled into polyester thread, which can be used to make clothing. While this does reduce the number of plastic bottles being thrown into the ocean, there is a limit to how helpful such a process is; the world only needs so many polyester shirts, and the need for plastic bottles will remain. The production of plastic bottles will continue, and it will outpace the rate of production for polyester shirts. Inevitably, many of those plastic bottles will wind up in the ocean [2.4].

In chemical recycling, plastic goods are broken down using chemical processes. The chemical structure of the plastic material is altered into a new material. For example, polyethylene plastic, which is one of the most prevalent types of plastic, is a polymer. It can be treated chemically so that it breaks down into hydrocarbons of varying lengths. There have been several studies in which plastic waste was converted to natural gas and oil using processes like pyrolysis and supercritical hydrothermal liquefaction on a lab scale [2.5, 2.6]. Natural gas and oil have several important uses, from making fuels to being refined into monomers that can be used as feedstock for plastic production. On an industrial scale, these processes could be used to create a direct path for plastic waste to be returned to new plastic products. As a result, less plastic waste would wind up either in the ocean or in countries unequipped to handle it.

Chemical recycling is not a well-established industry practice. There are strict limitations on what can be recycled. Current processes require plastic to be sorted into the different types before being recycled, which is a time- and energy-consuming endeavor. Plastic waste must also be clean before being processed. These constraints make chemical recycling financially, energetically, and feasibly unattainable; because of this, mechanical recycling and the dangerous aforementioned disposal processes are those most frequently practiced.

i. Introduction: Motivation and Goals

In completing this project, we set out to design a robust method to chemically recycle plastic waste in an affordable and efficient manner. The goal of our project was to convert 70 metric tons of plastic waste per day into clean plastic feedstock monomers—ethylene and propylene—which could then be sold to other facilities producing plastic. The feed would be a mixture of plastic types 2, 4, 5, and 6 (High-Density Polyethylene, Low-Density Polyethylene, Polypropylene, and Polystyrene, respectively). Plastic types 1 and 3 (Polyethylene Terephthalate and Polyvinyl Chloride) are not included in the feed because they contain non-hydrocarbon compounds, which could produce harmful byproducts (for example, chloride from the PVC) and would require extra processing beyond what is required for the specified types. Plastic type 7, which consists of any plastics that do not fall into categories 1-6, is also not included, because it is so ill-defined and would be impossible to predict how it would behave in our process.

We initially modeled our design for this process after a chemical recycling plant created by Plastic Energy, LLC, an English company that develops solutions for recycling plastic waste [5.7]. The process set forth by Plastic Energy, LLC boasted an ability to produce high-quality hydrocarbon fuels including naphtha, kerosene, and diesel from a mix of all plastic types through pyrolysis. From this point, further processing would be required to obtain the plastic feedstock monomers desired for the purposes of this project. Light hydrocarbon oils like naphtha are frequently used as feedstock in the production of short-chain hydrocarbons such as ethylene and propylene monomers, and methods to do so like steam cracking are well-established industrial processes. To successfully complete this project, we would need to unite these two processes within one chemical recycling plant, where a feedstock of plastic waste could be converted to light hydrocarbon oils and then processed further using standard industrial.

Over the course of completing this project, we determined that Plastic Energy, LLC's technology was not suited to our goal in producing ethylene and propylene monomers. However, the overall objective remained the same: to convert plastic waste into material that could then be used to produce ethylene and propylene. Because ethylene and propylene are very short hydrocarbon chains, it would be most desirable for the products from the initial pyrolysis to be as short in length as possible. The products of Plastic Energy, LLC's pyrolysis process were quite long hydrocarbon chains, ranging in length from four to more than twenty carbons. When it became clear that an alternative method of plastic degradation would be required, we turned to existing chemical recycling research and identified that pyrolysis of our plastic waste feedstock in a rotary kiln would provide us with a gas product that was well-suited for further processing into ethylene and propylene monomers.

From an economic perspective, our initial goal was to make this a profitable endeavor. Because our process uses plastic waste as its feed, we assumed that cities or other entities would pay us to collect their plastic waste. An additional goal was to determine the ideal location to build our plant; our choices were California, the Netherlands, and Indonesia. Ultimately, we chose Indonesia as the plant location, and found that the process would not breakeven after fifteen years of operation. The IRR for the plant is -4.47%, and the ROI in the third year of production is -2.01%.

In this report, we present our design of a chemical recycling plant that produces 33,600 pounds of 99.0 wt% ethylene and 30,000 pounds of 95.7 wt% propylene per day. This corresponds to a 20.67% yield of ethylene and a 19.48% yield of propylene, which is a 40.14% overall yield. The remaining products from the process include hydrogen and various hydrocarbons ranging in length from 1 to 4 carbons, which can be used as fuel for several of the process units. We also provide an economic analysis to determine the profitability of the plant.

ii. Introduction: Objective-Time Chart

Figure 5.1 shows the objective-time chart for the completion of this project.

	Task	Begin	End	January				February				March				April			
				5-11	12-18	19-25	26-31	1-8	9-15	16-22	23-29	1-7	8-14	15-21	22-31	1-11	12-18	19-25	26-30
1.	Basic Operation Specifications	Jan. 5	Jan. 25																
1.1	Research Upstream Processing	Jan. 5	Jan. 18																
1.2	Research Pyrolysis Unit	Jan. 12	Jan. 25																
1.3	Research Downstream Processing	Jan. 26	Feb. 15																
2.	Process and Equipment Design	Jan. 19	Mar. 21																
2.1	Basic Block Flow Diagram	Jan. 19	Jan. 31																
2.2	Preliminary Mass Balance	Feb. 1	Feb. 1																
2.3	Base Case Mass Balance	Feb. 9	Feb. 25																
2.4	Process Flow Diagram	Feb. 9	Feb. 25																
2.5	Software Modeling of Separations	Feb. 23	Mar. 21																
2.6	Pyrolysis Unit Design	Feb. 23	Mar. 21																
2.7	Steam Cracking Process Design	Feb. 23	Mar. 21																
	15-Minute Oral Presentation	Feb. 23	Mar. 3																
3.	Financial Evaluation	Mar. 8	Apr. 7																
3.1	Research Product Value	Mar. 8	Mar. 14																
3.2	Equipment and Material Costing	Mar. 15	Apr. 7																
3.3	Profitability Analysis	Mar. 22	Apr. 7																
4.	Report and Presentation	Mar. 28	Apr. 28																
4.1	Written Reports Due	Mar. 28	Apr. 14																
4.2	Revised Writte Reports Due	Apr. 17	Apr. 21																
4.3	Design Presentations	Apr. 14	Apr. 28																

Figure 2.1: Objective-Time Chart for the Completion of Mixed Plastic Waste to Ethylene and Propylene Feedstock.

Section 3. Market and Competitive Analysis

Ethylene, a volatile organic compound, is the most widely used hydrocarbon in the petrochemicals industry. Ethylene is used to form important chemicals such as ethylbenzene, ethylene glycol, and vinyl chloride. It is also the building blocks of #2 and #4 plastics, HDPE and LDPE. Like ethylene, propylene is a very important product in the petrochemical industry because it is also a feedstock to many B2B and B2C products such as, film fibers, polypropylene, cumene, and butyraldehyde. In 2019 the global ethylene production capacity was 207.58 million tons per annum (mtpa), with North America and Asia being highest producing regions [3.1], and in 2018 the global production capacity of propylene was 120 mtpa [3.2]. The main conventional techniques for ethylene and propylene production are steam cracking and catalytic cracking. In steam cracking, gaseous or liquid hydrocarbons, such as naphtha and liquefied petroleum gas, are diluted with steam and are cracked in a pyrolysis furnace. In catalytic cracking, longer hydrocarbons are cracked in the presence of catalysts at moderate temperatures. Still, both processes produce significant amounts of CO_2 emissions, with steam cracking alone contributing to 180 – 200 mtpa of CO_2 emissions worldwide [3.3].

Due to anthropogenic effects on the environment, ethylene and propylene production is shifting to unconventional methods to become more sustainable. This entails the use of biomass and implementing a circular economy within plastic production. Bioethylene, or renewable polyethylene, is made from ethanol after undergoing a dehydration process and also from bioethanol that originates from sugar cane, sugar beet, and wheat grain. The Coca-Cola Company uses this in their PlantBottle™ product, which is a polyethylene terephthalate (PET) bottle made from plants. The paraxylene used to create their PET bottles are sourced from bio-based iso-butanol [3.4]. Dow Chemical Company has also produced AGILITY™ CE, which is a resin made with 70% recycled LDPE. Fuenix Ecogy Group in the Netherlands also has patent to similar to that of Plastics Energy; in their process mixed plastic waste is burned in two successive pyrolysis furnaces and is then refined for further processing [3.5].

In this report we propose an unconventional process that uses a rotary kiln to pyrolyze 2,4,5,6 plastics. Our downstream process is the same of that in chemical plants that have a steam crackers. Though our ethylene and propylene output is not as large as conventional ethylene production plants, our process is unique because it establishes a circular plastic economy, with the potential for scale up. Currently, there are no industrial-scale chemical plants that process post-consumer and post-industrial plastic waste in a circular process. The unconventional methods mentioned work for specific uses, but they do not convert feedstock to ethylene and propylene. In addition, rather than drilling for feedstock, federal and local governments would pay for us to collect their plastic waste.

Section 4. Customer Requirements

Polyethylene and polypropylene product specifications must meet ISCC+ standards, in which recycling means, “any recovery operation by which materials are reprocessed into products, materials or substances whether for the original or other purposes.” Any diesel or fuel coproduct must comply with ASTM D975 or EN590 standards, and the minimum purity for polymer grade ethylene and propylene are both 99.5%. For propylene, the minimum purity for chemical grade is 95.0%.

Section 5. Preliminary Process Synthesis

i. Pyrolysis Process and Alternatives

a. Goal of Pyrolysis Chemistry

Existing research and operations regarding treatment of mixed plastic waste focus on the capacity to convert solid feed into liquid fuel, comparable to gasoline, kerosene, or diesel. Limited operations are used for the conversion of plastic waste to short-chain hydrocarbon gas product, and most gas produced is used a natural gas substitute to make cracking operations self-sustaining [5.1]. At present, industrial production of ethylene and propylene employs steam cracking to break hydrocarbons to C2 and C3. Common feeds for this process are ethane, propane, and naphtha, a light oil ranging from C5-C10 hydrocarbons [5.2]. Steam cracking using ethane or propane as feedstock runs the advantage of cheaper, less complex plants with high ethylene and propylene yield [5.1,3]. Additionally, it is well established that cracking of plastic waste produces a gas in the range of C1-C6, and an oil product in the range of C6-C24 [5.1]. The exact compositions of the oil and gas products will be discussed in greater detail in section 15. In the interest of achieving higher product yield and greater plant simplicity, the initial cracking reaction will thus focus on producing short-chain hydrocarbon gas product.

b. Considered Methods of Pyrolysis

Multiple vessels were considered for the primary cracking reaction in this process. As the initial treatment of plastic waste poses perhaps the greatest barrier to circular recovery of monomers, this stage in the process was explored extensively. The options considered as discussed below, and ultimately a decision matrix is used to justify the choice of a rotary kiln.

<u>Patent Provided in Project Statement</u>

As originally proposed, the project was to make use of a patent for “Conversion of Waste Plastics Material to Fuel” by David McNamara and Michael Murray. Their system employs a novel pyrolysis and contactor system, modeled as a CSTR, to convert dirty plastic feedstock to hydrocarbons ranging from C1-C21 [5.4]. However, due to an absence of available data and conflicting operating conditions, use of this technology was not possible [5.4,5].

Batch and Continuous Pyrolysis

Simple pyrolysis was considered as an alternative to the novel pyrolysis in the patent due to the abundance of data on the subject. Pyrolysis is the thermal degradation of long-chain polymers to small and less complex molecules through heating to temperatures in the range of 752 – 1472 ^{0}F, and is used primarily for the treatment of PE, PP, and PS [5.1]. Pyrolysis produces a gas product, liquid oil product, and solid char product. In practice, the production of liquid oil is often favored for use as a fuel oil due to its high calorific value, and the gaseous product is often used as a fuel source to make the pyrolysis unit self-sustaining [5.6]. Data exist to aid in prediction of products, and the unit is robust in ability to pyrolyze dirty plastic [5.1,6]. Pyrolysis is flexible in manipulation of operating variables to produce desired product, does not require extensive feed sorting, and may not require feed cleaning [5.7]. Notably, pyrolysis data is lacking in study of mixed plastic feed and is susceptible to the random nature of the cracking reaction [5.8].

The batch pyrolysis reactor is most commonly studied in literature. Batch pyrolysis is useful in manipulation of residence time and simplicity of unit design. However, batch pyrolysis suffers from variable product composition, and on the scale of this project, the size of a batch pyrolysis reactor is not realistic (estimated at slightly over 1,000 ft^3) [5.9]. In contrast, when operated continuously, greater consistency in product composition is achieved and capacity increases significantly [10]. Both units require a residence time of 15-60 minutes, which presents obstacles for handling large feed quantities [5.1,6,10].

Pyrolysis runs the major disadvantages of heat transfer and ease of operation. Heat transfer is most commonly achieved via passage of an inert gas on an industrial pilot scale [5.11].

However, this process is to focus on the product of gaseous product, and oxygen-rich gas may not be used due to the favorable formation of CO and CO_2, nitrogen gas proposes a complex separations problem, and other carrier gases are too expensive on the required scale [5.1]. Additionally, both types of pyrolysis require high operation cost due to oil and char accumulation, and variable product composition [5.1].

Liquefaction

Hydrothermal liquefaction is a thermal depolymerization process that converts hydrogenated biomass into oil-like product, often in the presence of a catalyst [5.13]. Liquefaction is used for treatment of plastic waste due to the lower heat requirement (waste need be heated in the range of 300-500 ^{O}C), robustness of the process to handle multiple types of plastic, and ability to process wet and dirty feedstock [5.12,13]. Liquefaction has been shown to give high yield of oil product (around 90% by weight of feed) and with residence times of 30-60 minutes, which is comparable to pyrolysis. [5.13,14].

However, liquefaction requires high pressures, on the order of 30 atm, which are difficult to achieve in large vessels prior to the production of gaseous product [5.12]. Additionally, the liquefaction process is used primarily to generate oil product, and in the studies here considered gives a maximum gas yield of less than 20% by weight of feedstock [5.12,13,14]. Finally, liquefaction often requires a catalyst for high conversion rates of the feedstock to oil product, which is undesirable for reasons considered in section 13.2.9

Fluidized Bed

The fluidized bed has the major advantages of efficient heat transfer and short residence time [1]. Additionally, a fluidized bed has been used in previous pilot-scale work termed the Hamburg Process for conversion of plastic waste to fuel gas [5.15]. It has the advantages of moderate maintenance cost, ease of catalyst introduction, and formation of gaseous product (which is favored in our process) [5.1,16]. However, the operation of a fluidized bed for treatment of viscous liquid is complex and requires the bed to be filled often with expensive material [5.17]. Issues arise with plastic melt sticking to the surface of the bed material and the unit and scale up becomes complex [5.18]. Additionally, massive amounts of nitrogen effluent are required, estimated at by calculation, and therefore present significant challenges to achieving product purity. Finally, the fluidized bed is primarily used to form methane gas for use as a natural gas substitute, and conversion of methane to ethene and propene on an industrial scale is unfeasible due to catalyst and electromagnetic radiation requirements [5.1,19].

<u>Rotary Kiln</u>

The rotary kiln has little data available and has rarely been used to treat plastic waste. However, under the assumption that the rotary kiln behaves much like a continuous pyrolysis unit, the expected product and composition may be estimated. The rotary kiln may handle large amounts of plastic waste and offers significant control over the residence time as a function of angle. Heat transfer in the kiln is difficult but may occur without introducing an effluent gas and thus reduce the need for complex separation. Additionally, through a cleverly designed indirect fired kiln, the necessary heat transfer may be achieved due to the nature of a moving liquid in the reactor. The rotary kiln is also expected to require minimal maintenance, as the angular nature aids in removal of viscous liquid and char.

<u>Evaporator</u>

An evaporator was explored as an alternative due to the desire of forming gaseous product, and their efficient heat transfer. Evaporators are already used in the handling of hydrocarbons, predominately in the fuel industry for removal of water from crude oil. However, the evaporator is not used at the temperatures required for the pyrolysis of plastic waste, is not used in practice for reactions, and presents challenges with transport of viscous fluid.

Spouted Bed

The sprouted bed reactor has been explored for treatment of plastic waste as a theoretically sound option for treatment of plastic waste to address the defluidization and bed segregation issues accompanying a fluidized bed [5.20]. It is able additionally to handle the viscous molten plastic without need for significant operating cost associated with cleaning [5.21]. However, the spouted bed reactor is most suitable for producing gasoline-range hydrocarbons in oil form and has a complex design with high pumping requirements [5.22,23]. Additionally, the design requires a catalyst, which is not favorable for industrial scale action [5.24].

Use of a Catalyst

Catalysts are commonly used in plastic waste pyrolysis for enhancing yield and promoting gasoline-range hydrocarbons. Little work has been done to encourage the formation of gaseous product, but H-ZSM-5 and red mud have emerged as potential catalysts to promote gas formation. The greatest challenge with catalyst uses on the scale of this project is recycle, due to the viscous nature of the plastic and oil product [5.25]. In the case of a fluidized bed, catalyst recycle is feasible, but beyond this system recycle becomes complex and energy consuming.

c. Decision Matrix

Many characteristics of the mentioned systems were considered and synthesized into a decision matrix (Table 13.1). The rotary kiln option was found to be the only option with no apparent major design challenges and was thus selected for the process.

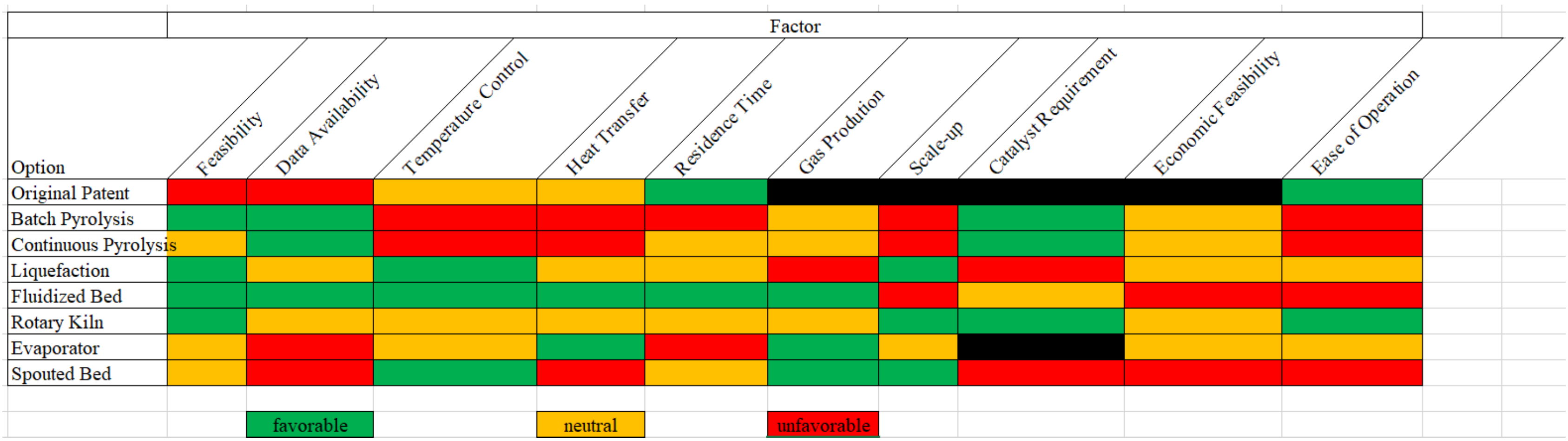

Table 5.1 Decision Matrix

ii. Secondary Cracking Operation

The gaseous product of the rotary kiln does not contain enough ethylene and propylene to separate and sell, thus further cracking is required to obtain desired products. As it is well established in industry and is the traditional method of ethylene and propylene production, steam cracking was selected for the secondary cracking operation. The subsequent operations on the steam cracking product, involving transfer line exchange, quench, and purification were implemented. In practice, this process often uses a caustic tower for the removal of acidic gas (such as sulfur contamination and CO), and a molecular sieve dryer for removal of steam from the product stream. However, given the assumptions of this project, these two units are not necessary.

The chemistry of steam cracking is thankfully well known. The cracking yields were approximated using the distribution provided by Akah [5.41] and given in Table 5.2.

Yield by weight	Ethane (%)	Propane (%)	Butane (%)
Hydrogen and methane	13	28	24
Ethylene	80	45	37
Propylene	2	15	18
Butadiene	1	2	2
Mixed butenes	2	1	6
*C*5+	2	9	13

Table 5.2 Steam Cracking Yields

To determine the distribution, hydrogen, methane, ethene, and propene were assumed inert in the steam cracker. Ethane, propane, and butane were assumed to crack according to the distribution of table 5.2. Butane was used to represent butane, butadiene, and all C5+ compounds for energy balances and separations. The product composition, given as weight percent from the steam cracker, is therefore given in Table 5.3

Species	% Weight
H_2 and Methane	23.5
Ethane	4.2
Ethene	38.3
Propane	1
Propene	24.9
C4+	8.0

Table 5.3 Steam Cracking Outlet Composition

iii. Self-Sustaining Fuel Considerations

The pyrolytic liquid of the rotary kiln has value as a fuel oil. The composition of the oil and product distribution are estimated in section 15. Due to the partly unknown nature of the compounds in the oil and the major heat requirements of the rotary kiln and steam cracker, all the pyrolytic oil produced is used as fuel. Additionally, due to the small amount of oil produced (1181 lb/hr), a separation train to provide on-specification commercial fuel product is not economically viable.

iv. Separation Process and Alternatives

a. Separations Goal

The goal of the separation process was to achieve a split between our final monomer products, ethylene and propylene, and the rest of the hydrocarbons produced in the steam-cracking unit that were to be used as fuel. Additional separation processes were also considered in conjunction with some of the alternative pyrolysis methods that were considered.

b. Extractive Distillation

In certain studies, it was found that a significant amount of aromatic species would be produced in the pyrolytic oil. The aromatic species estimated to be in the pyrolytic oil were benzene, toluene, xylene (BTX), naphthalene, and styrene. We considered using extractive distillation to remove BTX and the other aromatics from the pyrolytic oil, to sell them together or separately. To do this, all products from the rotary kiln will be sent to an extractive distillation column where a solvent would be feed from the top of the column. The aliphatic species would exit in the column overhead, while the aromatic species and solvent would leave in the bottoms and be fed to another tower where they would be separated. The solvent would leave in the overhead of the second column and would be recycled back to the first column. The solvent we considered using was Tetrahexly ammonium-bromide. We decided against this process given that capital costs of trying to separate the aromatics further, and the hazards of having solvent in the light gas stream flowing into the steam cracker.

c. Separation Train Design

<u>One-Stage Flash Alternative</u>

One method that was considered for the separation process was to include a one-stage flash vessel as the first separation event, to remove the lightest components, hydrogen and methane. However, because all of the components being separated are quire light and have low boiling points, achieving this separation in a flash vessel would require either extreme pressures (on the order of 10,000 psia) or extreme temperatures (nearing -425°F). Only at these conditions will the desired products, hydrogen and methane, exist in the vapor phase while the rest of the products stayed in the liquid phase. This approach was also tested using ASPEN, and the simulation confirmed the predicted outcome. It was clear that tray towers would need to be used, which are what is used in industrial petrochemical plants that process similar product streams.

Demethanizer Column Design

The separation train configuration was modeled after standard industrial separation processes in ethylene and propylene plants. In the industry, feeds of refined hydrocarbons with hydrogen are sent into a demethanizer column, a type of distillation column that separates the lightest gasses (methane and hydrogen) from heavier hydrocarbons. Demethanizer columns require extremely low temperatures, and designing these columns is much less straightforward than a standard distillation column that can be run at more typical operating conditions.

The separation would occur between the light key, ethylene, and the heavy key, methane; we wanted to recover our hydrogen and methane in our distillate, and all of our hydrocarbons heavier than methane in our bottoms product. We knew that a total condenser would be implausible. The critical temperature of hydrogen is -400ºF, which is less than 100ºF above absolute zero temperature. Clearly, the distillate exiting the demethanizer would be a vapor. So, for our first pass at the design using ASPEN, we initially selected a partial condenser with all vapor distillate and set the column pressure to 450 psia (a reasonable guess for a distillation column with such a light distillate product, per *Seider et al*) [5.26].

Using DSTWU in ASPEN as a first attempt for column design, we found that the required condenser temperature to achieve a successful split between the components (i.e., removing 99% of the light key) was -230ºF. While condensers for demethanizer columns do operate at extremely low temperatures, they usually hover around -130ºF; any colder and the energy requirements become too great to be feasible. So, we increased the pressure of the column to bring the temperature of the distillate up to a more reasonable value. Even at an unrealistically high pressure of 1000 psia, the distillate was *still* coming out of the column around -220ºF; it was clear that increasing the pressure of the column would not be sufficient in increasing the distillate temperature.

One reason that the distillate would need to be at such a low temperature was that the other components being separated from the hydrogen and methane were also very light. Ethylene's normal boiling point is -154.7ºF, and that is the lightest of the heavy hydrocarbons. To obtain a split between methane and ethylene, an extremely low temperature would be needed. Rather than increase the pressure to an extremely high number, it would be more sensible to allow some of the ethylene to exit the column from the top of the column, which would increase the temperature required in the condenser. This would also allow us to operate the condenser at a more reasonable pressure of 550 psia. The downside of this is that some of the ethylene product is lost and cannot be recovered (for the same reason that it could not be recovered in this column), but we did not consider this to be a total loss—the ethylene that exits through the top of the demethanizer column could be used as fuel elsewhere in the process and would be valuable to the process in that regard.

To implement this into the design, the demethanizer column was modeled in ASPEN as a RadFrac column using a partial-condenser with vapor and liquid distillate. After some trial-and-error to determine what amount of ethylene would allow the demethanizer condenser temperature to reach a more reasonable value, a distillate flowrate of 1,702 lbs/hr and a vapor fraction of 0.448 was chosen. The vapor distillate also contained 539 lbs/hr of ethylene, though, to increase the temperature of the condenser, as discussed above. Most of our ethylene product (1,437 lbs/hr) exited the column in the liquid distillate stream, meaning that we were recovering a significant portion of the ethylene product in our first distillation event. However, the ethylene recovery stream still contained several other components.

Deethanizer

The deethanizer column would need to perform a similar function to the demethanizer column—removing the remaining methane from the ethylene recovery stream. The same challenges related to the demethanizer column also held true for the deethanizer column; the condenser would need to operate at a very low temperature to allow for separation between the very light components. Originally, a partial-condenser with vapor and liquid distillate was tested, but upon closer examination, it appeared that the concentration of ethylene became greater lower in the column, so a side-stream was taken off the column instead. This meant that a partial-condenser with all vapor distillate would need to be used. Again, some ethylene was permitted to exit the top of the column to allow for a more reasonable condenser temperature.

Depropanizer

The bottoms products from both the demethanizer and deethanizer column are sent to the depropanizer for separations. The remaining components in the separations process were heavy enough that a higher condenser temperature of -29.06ºF could be used. A partial-condenser with vapor and liquid distillate was considered, but, similar to the deethanizer, taking off a side stream resulted in better propylene yield, and a purer propylene product.

One modification to the process that could result in better propylene product yield would be to add the two feed streams to the depropanizer column at different stages based on their composition. In the stream from the demethanizer, there is a higher mass fraction of butane, which is the heaviest component; it would be worth trying to feed this stream at a lower stage than the stream from the deethanizer, which has a higher mass fraction of lighter components. Doing so could potentially reduce the amount of energy required in the separations. Throughout the column, the composition of heavy components increases toward the bottom of the column, and the composition of light components increases toward the top of the column. A feed with more heavy components that is fed to the top of the column will require more energy for separations than if that same feed is fed closer to the bottom of the column, since the upper stages have to do less work separating those heavy components. This logic also applies to feed streams that have more light components—such streams should be fed higher up in the column.

v. Material Balances

Central to understanding the operation of the rotary kiln is determining amount and composition of each of the products exiting the rotary kiln. As the rotary kiln model is new in the treatment of plastic waste, data from batch pyrolysis units will be used to determine the products of the kiln reactor. The following analysis is best considered as a theoretical template exclusively. In practice, the cracking reactions of interest are random in product distribution, and subsequently published data lacks consensus on product distribution. A pilot plant would be necessary to determine the actual composition of the products of the rotary kiln.

The percent of feed converted to gas is of primary interest. The production of gas in the kiln is dependent on pressure, temperature, feedstock, and residence time. High temperature and long residence time are most important for maximizing raw production of gas [5.27]. However, residence time beyond a threshold has minimal impact on gas yield [5.28], and temperatures above 700^{o}C favor the production of hydrogen and methane, which are not useful in forming ethylene and propylene [5.29]. Additionally, pyrolysis is not well studied above temperatures of 650^{o}C is not well studied [5.27]. and cracking performed at temperatures above this often use fluidized bed reactors.

We adopt the gas conversion value found by Lopez et. Al. that at 600 ^{0}C, 56.2% of the feed is converted to a gaseous phase, as this study most reflects the pressures we intend to use and the feed composition we propose [5.30].

The residence time is also of interest and expected to play a significant role in the production of gaseous product in the rotary kiln. Again, studies focusing on the residence time are inconclusive, and unfortunately only two studies have analyzed the impact of residence time on non-homogeneous plastic waste samples and gave conflicting results. Adopting the findings of one study and assume that being held at high temperature for up to 30 minutes continues to aid in the formation of gaseous product, but a pilot scale plant would be required to determine the true impact of residence time [5.29].

An additional impacting factor is the heating rate of the plastic feed. In most experiments, a 20^{0} C/min heating rate is used. Therefore, the rotary kiln is designed such that the heating rate is at minimum 20^{0} C/min, but it is recognized that a heating rate higher than this is achievable and may aid in the production of more gaseous product.

To determine the ultimate amount of gas produced in the rotary kiln, the following assumptions are made. First, the Lopez et. Al. value of 56.2% is used to determine that in heating to 600^{0} C, 56.2% of the inlet is converted to a gaseous state. Extrapolating one data set of residence time dependence, it may be expected that after reaching the reaction temperature, maintaining the temperature for 30 minutes will give an overall gaseous yield of 65.9% by weight [5.28]. However, in an optimistic approach, we assume that those reactions which produce gas in the initial 30-minute heating period of the Lopez study repeat in a second 30-minute heating period, and thus 56.2% of the oil produced after 30 minutes is again converted to gaseous phase. This gives an ultimate conversion of 80.3 % weight of the inlet molten plastic to a gaseous state.

The rotary kiln is designed according to the parameters hereby assumed. Ultimately, the assumed conversion is relatively arbitrary, but we expect that in a pilot plant, by controlling residence time, temperature, pressure, and heating rate, that 80.3% conversion to gas is feasible. Thus, the downstream operations need not necessarily be scaled to drastic changes in the outlet of the rotary kiln reactor.

Gaseous product composition

The gas product exiting the rotary kiln is known to be exclusively short chain (C1-C6) hydrocarbons and hydrogen gas. The exact composition is known to be a function of temperature and residence time (both to a threshold) and is likely dependent on pressure and heating rate as well. The composition used henceforth in this process design is that presented by Lopez. Et. Al. for a reactor temperature of 600^0C and residence time of 0 minutes once said temperature is achieved (table 15.1). Several changes are made to the published distribution. As the Lopez study includes PET in the feed, CO and CO_2 are formed. As this is impossible in an oxygen-free rotary kiln, these products are scaled out of the ultimate distribution. Additionally, the Lopez distribution 9.5% by weight of C5 and C6, which is semi-consistent with other published distributions. Due to the availability of steam cracking data, C4-C6 are lumped together as butane for downstream mass balances. Thus, by weight, the gas product distribution is presented in table 5.4.

0.72	Hydrogen
13.36	Methane
10.59	Ethane
19.84	Ethene
10.09	Propane
18.90	Propene
26.52	Butane

Table 5.4 Pyrolytic Gas Composition

Liquid product composition:

The distribution of liquid products is less understood than that of gaseous, due to greater variation in larger carbon chains. For consistency, the Lopez distribution is again used, although this distribution is arbitrary and only important for understand the thermodynamic value of the oil outlet. The distribution accounts for only 78.5% of the oil outlet, and is thus scaled both for the absence of oxygenated compounds and to account for those molecules not otherwise recorded in the study:

Toluene	22.29
ethylbenzene	10.32
xylene	5.73
styrene	41.27
α-methyl-styrene	5.61
naphthalene	8.28
methylnaphthalene	6.50

Table 5.5 Pyrolytic Oil Composition

Using this distribution, the properties of the oil are estimated. Notably, the heat of combustion is taken as a weighted average of the known species as 4289 kJ/mol.

vi. Feed Assumptions

The availability of waste plastic is complex insofar as most plastic is sent to landfills and is not sorted or recycled. For example, an estimated 10% of plastic waste in the United States is recycled, meaning that nearly 27 million tons is annually sent to landfill [5.31]. This plastic is not sustainable as a feedstock. However, there exist Materials Recovery Facilities and private companies which specialize in treatment and recovery of plastic waste. Plastic waste is solid in a variety of forms, potentially as curbside, contaminated waste, processed and cleaned bales, or sorted and shredded shards. Additionally, HDPE, LDPE, PP, and PS are all available in varying amounts. Therefore, a consistent homogenous feedstock is unlikely for this process, and the following assumptions are made.

The composition of the plastic feed is approximated by scaling production data since 1950 to account for just the four types of interest [5.32]. The feedstock is hereby assumed to be composed by weight of the values in Table 5.4, and properties of the feedstock are estimated as a weighted average of the four types of plastic:

Plastic Code	Plastic Type	Percent by weight
II	High-Density Polyethylene	23.2
IV	Low-Density Polyethylene	27.9
V	Polypropylene	37.2
VI	Polystyrene	11.6

Table 5.6 Plastic Feed Composition

The feedstock is additionally assumed to be pre-washed, pre-dried, and pre-shredded. Plastic waste contains an average of 7% by weight of additives, such as dyes and structural enhancers, which are assumed to remain in the feedstock. The plastic shards are estimated to be

100mm flakes, as is standard for recycled waste [5.33]. The feedstock is likely to arrive in varying amounts of each type of plastic, but this does not impact the process design or operating conditions. As priced from a weighted average of multiple online sources, this feedstock costs an estimated \$0.19/lb [5.34-5.40]. This cost is attributed to the transport, cleaning, sorting, and shredding of the plastic waste. The feed stock is additionally assumed to have density of 58.9 lb/ft^3 and heat capacity of 0.442 BTU/ lb ^{0}F.

Plastic washing, cleaning, drying, sorting, and shredding are well-established processes for which the required units may be purchased as needed to account for different feeds. Companies such as Herbold Meckesheim and MG Machinery offer entire plastic treatment lines which handle all the aforementioned waste treatment steps for industrial purchase, as well as individual line components. Therefore, although this design assumes a shard feedstock, other units may be purchased to account for variability in plastic waste feed.

Section 6. Process Flow Diagrams and Stream Tables

i. Block Flow Diagram

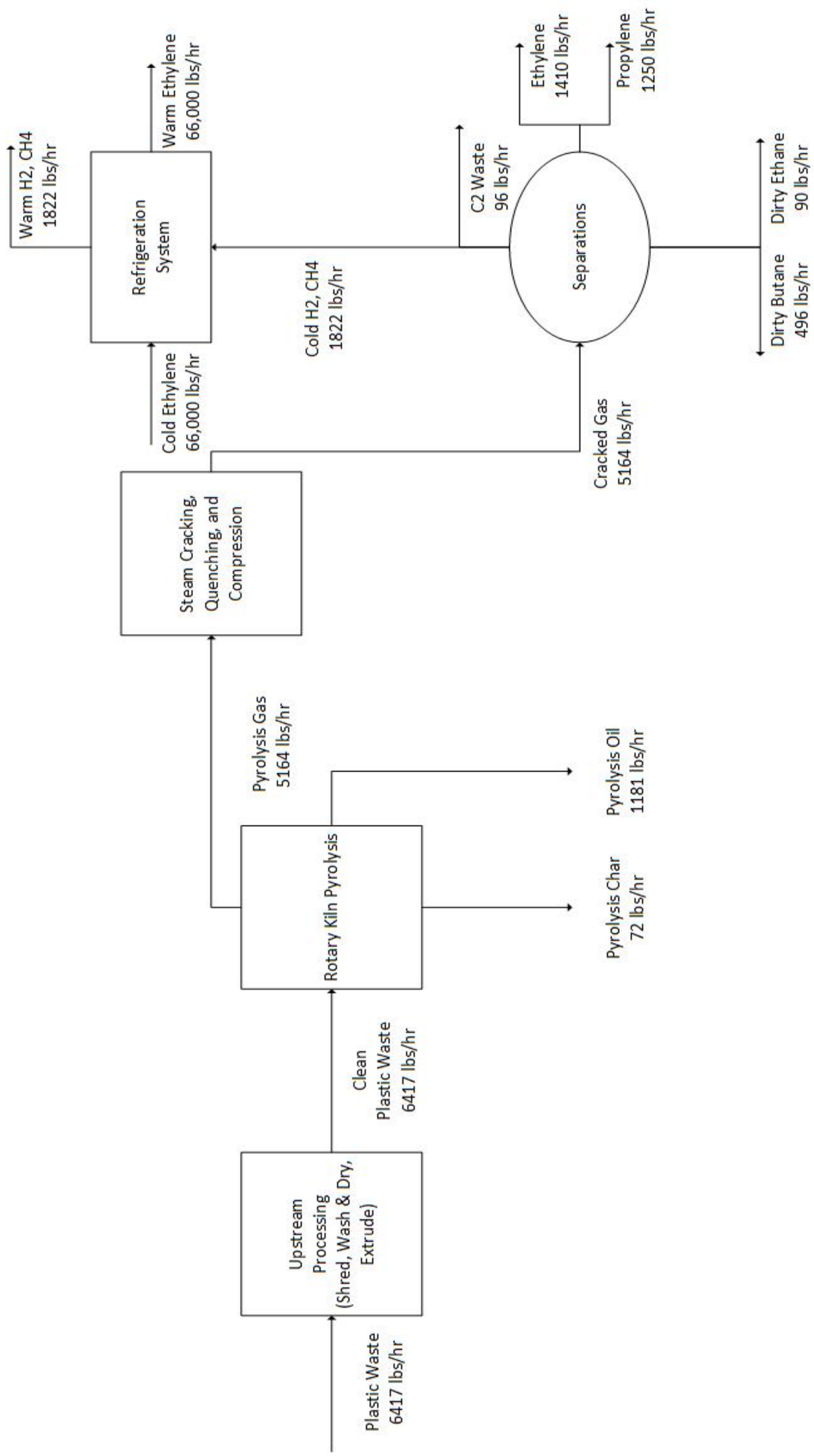

Figure 6.1: Block Flow Diagram

ii. Section 000: Upstream Processing

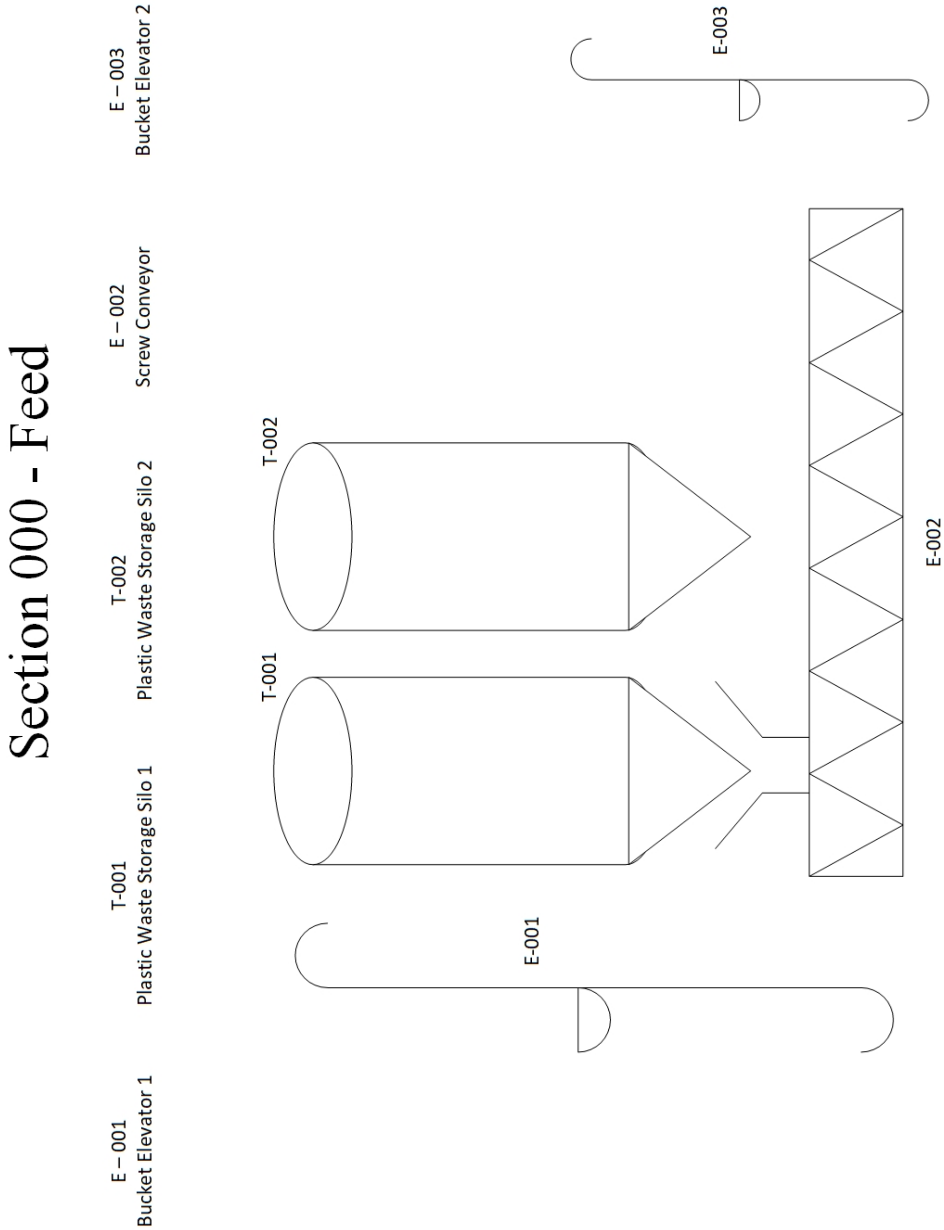

Figure 6.2: Section 000 PFD

iii. Section 100: Rotary Kiln Pyrolysis

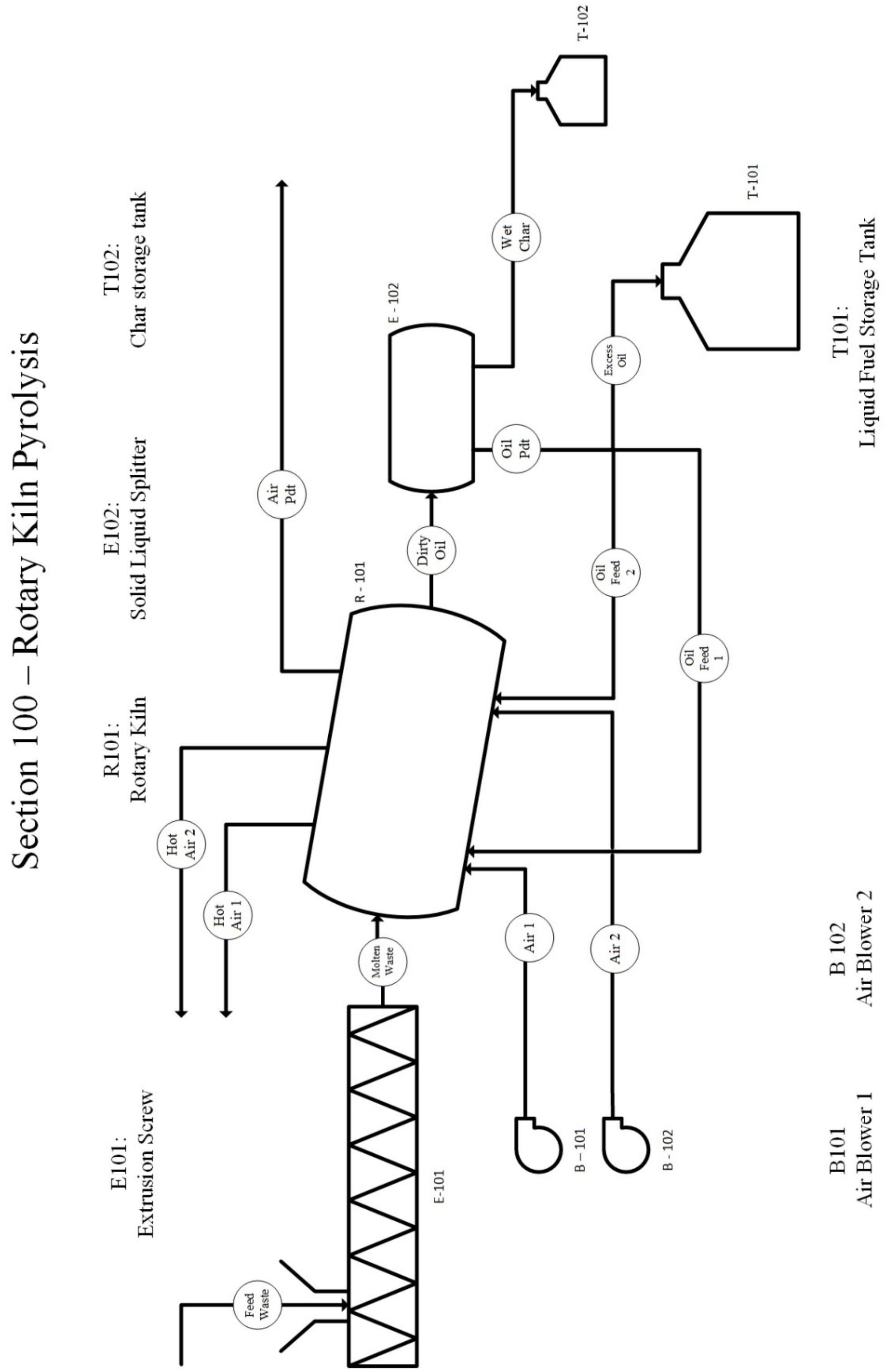

Figure 6.3: Section 100 PFD

Stream	Feed Waste	Molten Waste	Air Pdt	Dirty Oil	Oil Pdt	Oil Feed 1	Oil Feed 2	Excess Oil	Wet Char	Air 1	Air 2	Hot Air 1	Hot Air 2
Phase	solid	liquid	gas	liquid/solid	liquid	liquid	liquid	liquid	liquid/solid	gas	gas	gas	gas
Temperature (F)	77	482	1112	1112	1112	1112	1112	1112	1112	77	77	1292	1292
Pressure (psia)	14.7		73.5	73.5	73.5	73.5	73.5	73.5	73.5	14.7	14.7	36.8	36.8
Flow Rate (lb/hr)	6429	6429	5163	1265	1003	306	20	675	262	7045	459	7594	692
Component Flow Rates (lb/hr)													
Polyethylene	3291	3291											
Polypropylene	2392	2392											
Polystyrene	746	746											
Hydrogen			37										
Methane			690										
Ethane			547										
Ethene			1024										
Propane			521										
Propene			975										
Butane			1369										
Toluene				263	224	68	4	150	39				
ethylbenzene				122	104	32	2	70	18				
xylene				68	57	18	1	39	10				
styrene				487	414	126	8	279	72				
a-methyl-styrene				66	56	17	1	38	10				
naphthalene				98	83	25	2	56	14				
methylnaphthalene				77	65	20	1	44	11				
water vapor												437	216
Carbon Dioxide												112	17
air										7045	459	7045	459
Carbon				84					84				

iv. Section 200: Steam Cracking, Quen ching, and Compression

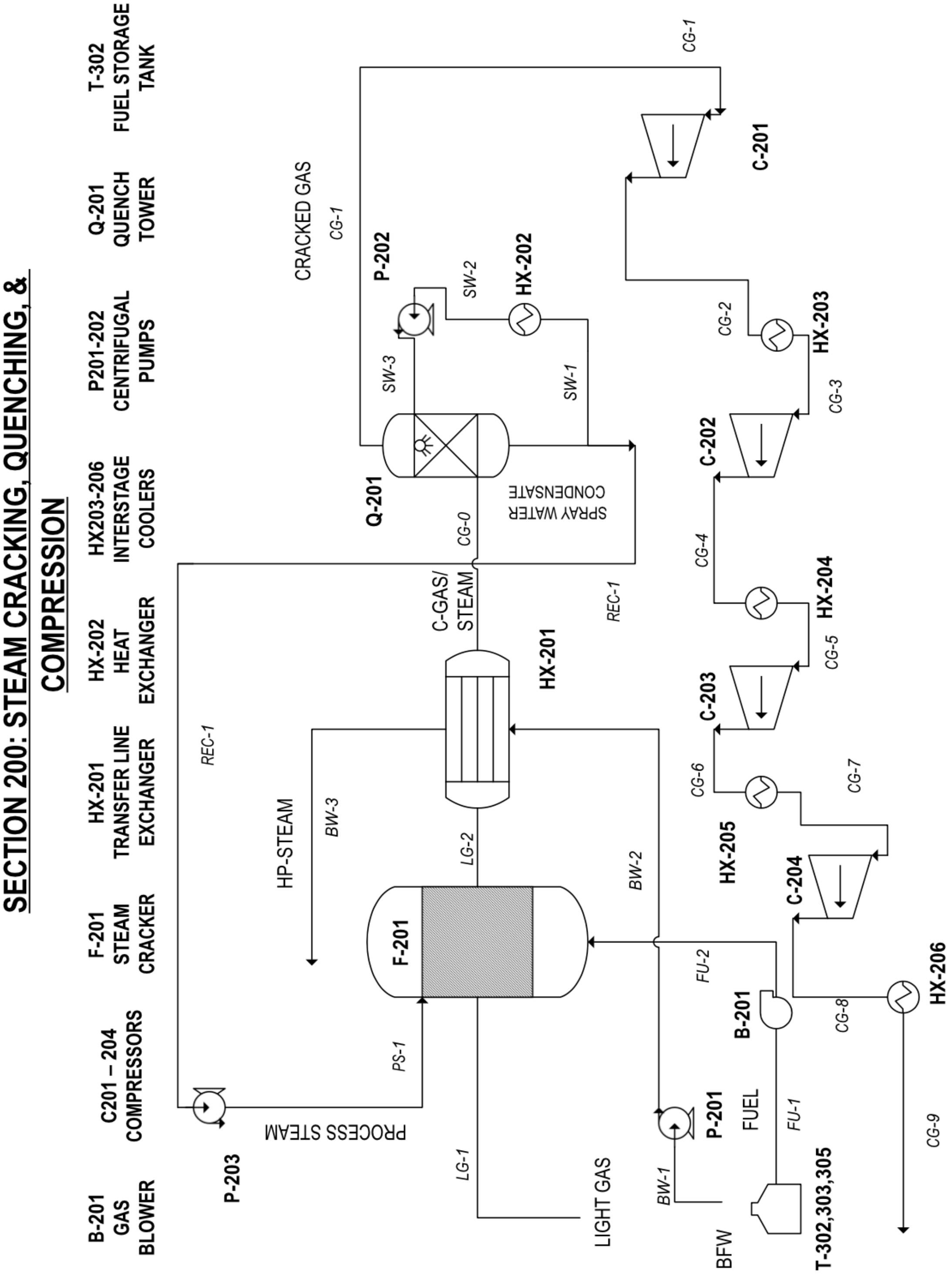

Figure 6.4: Section 200 PFD

Stream	BW-1	BW-2	BW-3	LG-1	LG-2	CG-0	CG-1	CG-2	CG-3	CG-4	CG-5
Temperature (ºF)	212.00	100.00	600.00	1,112.00	1,472.00	752.00	100.00	324.32	224.32	326.71	226.70
Pressure (psia)	50.00	470.00	450.00	72.52	67.00	60.00	43.50	158.50	158.50	273.50	273.50
Mass Flow (lbs/hr)	4,163.00	4,163.00	4,163.00	5,163.00	7,229.00	7,229.00	5,163.00	5,163.00	5,163.00	5,163.00	5,163.00
Component Mass Flow (lb/hr)											
Hydrogen	-	-	-	36.00	606.00	606.00	606.00	606.00	606.00	606.00	606.00
Methane	-	-	-	690.00	606.00	606.00	606.00	606.00	606.00	606.00	606.00
Ethylene	-	-	-	1,024.00	1,978.00	1,978.00	1,978.00	1,978.00	1,978.00	1,978.00	1,978.00
Ethane	-	-	-	547.00	219.00	219.00	219.00	219.00	219.00	219.00	219.00
Propylene	-	-	-	975.00	1,287.00	1,287.00	1,287.00	1,287.00	1,287.00	1,287.00	1,287.00
Propane	-	-	-	521.00	58.00	58.00	58.00	58.00	58.00	58.00	58.00
Butane	-	-	-	1,370.00	409.00	409.00	409.00	409.00	409.00	409.00	409.00
Water	4,163.00	4,163.00	4,163.00	-	2,066.00	2,066.00	-	-	-	-	-
Stream	CG-6	CG-7	CG-8	CG-9	REC-1	PS-1	SW-1	SW-2	SW-3	FU-1	FU-2
Temperature (ºF)	292.15	192.15	258.31	142.31	120.00	120.00	120.00	90.00	90.00	70.00	292.90
Pressure (psia)	388.50	388.50	559.50	559.50	21.00	250.00	40.00	35.00	60.00	14.70	54.70
Mass Flow (lbs/hr)	5,163.00	5,163.00	5,163.00	5,163.00	2,066.00	2,066.00	185,480.00	185,480.00	185,480.00	1,787.00	1,787.00
Component Mass Flow (lb/hr)											
Hydrogen	606.00	606.00	606.00	606.00	-	-	-	-	-	606.00	606.00
Methane	606.00	606.00	606.00	606.00	-	-	-	-	-	599.00	599.00
Ethylene	1,978.00	1,978.00	1,978.00	1,978.00	-	-	-	-	-	582.00	582.00
Ethane	219.00	219.00	219.00	219.00	-	-	-	-	-	-	-
Propylene	1,287.00	1,287.00	1,287.00	1,287.00	-	-	-	-	-	-	-
Propane	58.00	58.00	58.00	58.00	-	-	-	-	-	-	-
Butane	409.00	409.00	409.00	409.00	-	-	-	-	-	-	-
Water	-	-	-	-	2,066.00	2,066.00	185,480.00	185,480.00	185,480.00	-	-

v. Section 300: Separations

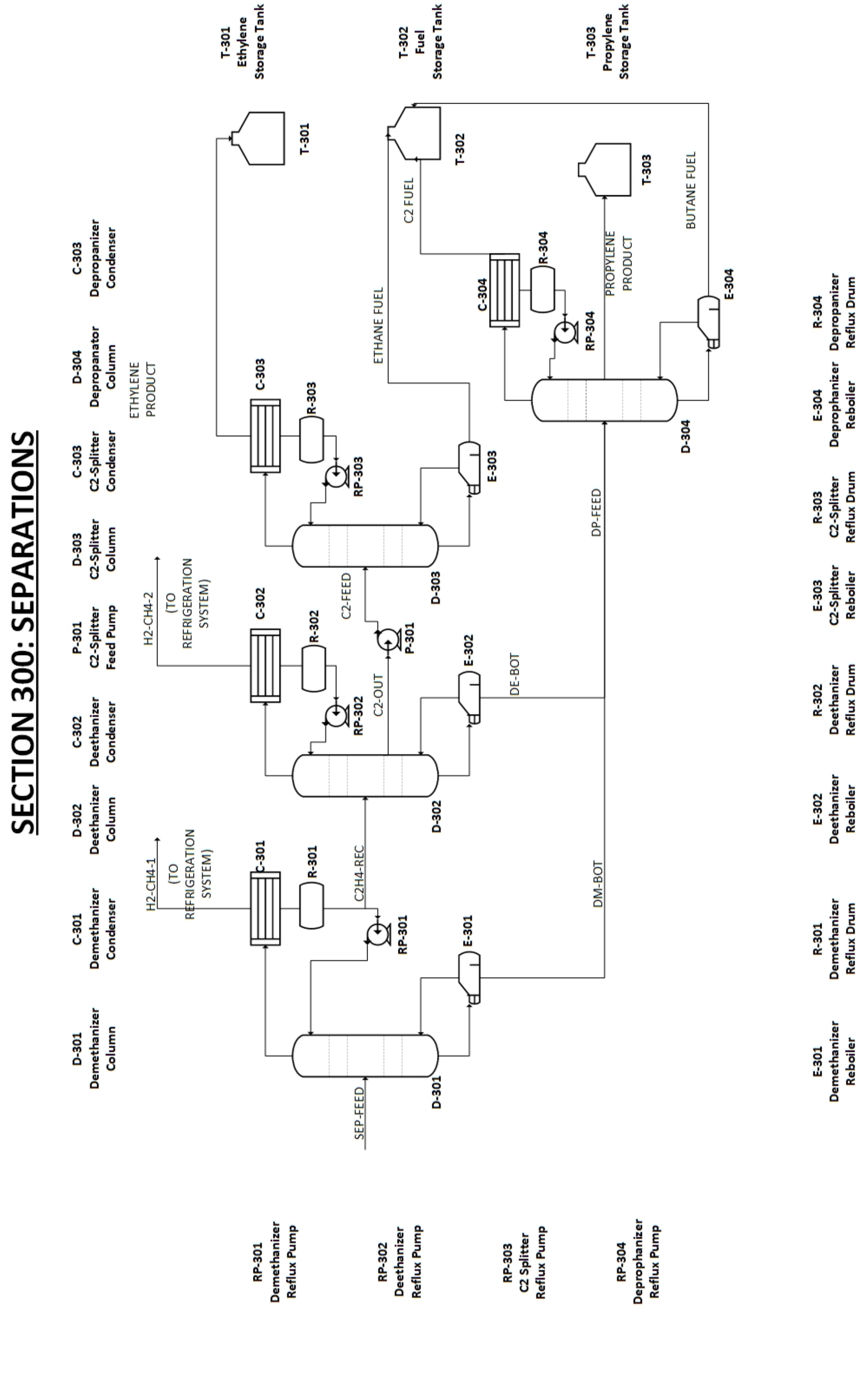

Figure 6.5: Section 300 PFD

Stream	SEP-FEED	H2-CH4-1	C2H4-REC	DM-BOT	H2-CH4-2	C2-OUT	C2-FEED	DE-BOT	ETHYLENE PRODUCT	ETHANE FUEL	DP-FEED	C2 FUEL	PROPYLENE PRODUCT	BUTANE FUEL
Temperature (ºF)	142.5	-131.2	-131.2	205.1	-129.8	-44.2	-41.3	57.5	-20.6	17.3	103.2	-11.3	69.2	149.1
Pressure (psia)	503.5	550	550	554.4	200	203.56	290	207.2	290	296.2	207.2	150	154.1	156.9
Mass Flow (lbs/hr)	5164.04	1702.40	2097.60	1364.04	120.00	1500.00	1500.00	475.18	1410.00	90.00	1841.64	96.00	1250.00	495.65
Phase	L	V	L	L	V	L	L	L	V	L	MIXED	V	L	L
Component Mass Flow (lb/hr)														
Hydrogen	606.59	603.97	2.63	0.00	2.61	0.02	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Methane	606.59	515.34	91.25	0.00	84.02	7.23	7.23	0.00	7.23	0.00	0.00	0.00	0.00	0.00
Ethylene	1978.94	538.98	1437.05	2.90	33.24	1400.90	1400.90	2.91	1395.98	4.92	5.82	5.33	0.49	0.00
Ethane	218.66	35.37	181.05	2.24	0.13	91.86	91.86	89.06	6.78	85.08	91.30	79.68	11.62	0.00
Propylene	1286.89	8.55	373.42	904.92	0.00	0.00	0.00	373.42	0.00	0.00	1278.34	10.88	1196.54	70.91
Propane	52.08	0.16	9.78	42.14	0.00	0.00	0.00	9.78	0.00	0.00	51.92	0.11	40.85	10.96
Butane	414.29	0.02	2.42	411.84	0.00	0.00	0.00	2.42	0.00	0.00	414.27	0.00	0.50	413.78
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

vi. Section 400: Refrigeration System

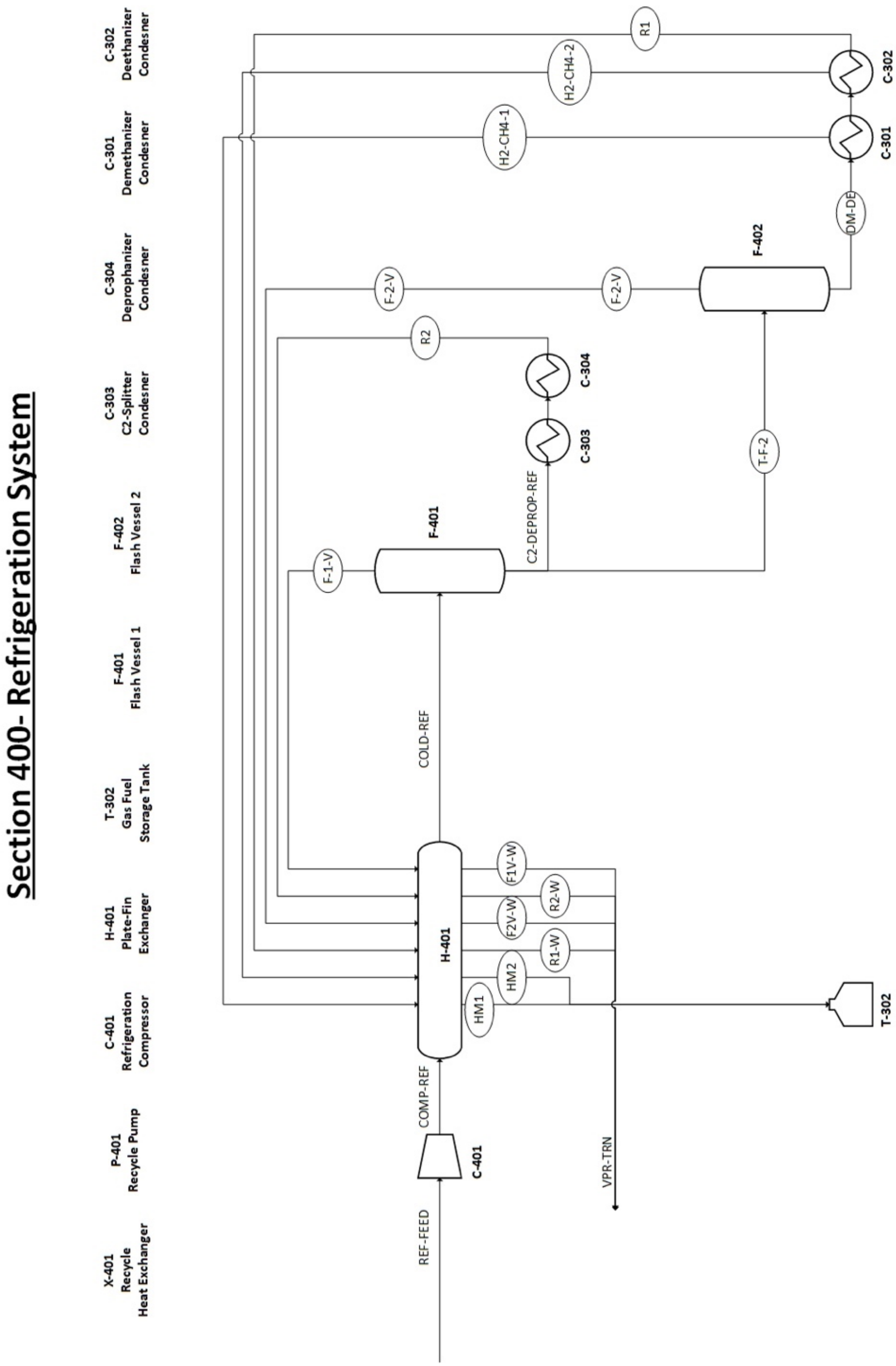

Figure 6.6: Section 400 PFD

Stream	REF-FEED	COMP-REF	COLD-REF	F-1-V	C2-DEPROP-REF	T-F-2	F-2-V	DM-DE	H2-CH4-1	H2-CH4-2
Temperature (ºF)	85	100	4.6	-29.06	-29.06	-29.06	-143.69	-143.69	-131.2	-129.8
Pressure (psia)	30	2000	2000	252	252	252	21	21	550	200
Mass Flow (lbs/hr)	66000.00	66000.00	66000.00	8397.41	19000.00	38602.59	13676.95	24925.63	1702.22	120.00
Component Mass Flow (lb/hr)										
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	603.97	2.61
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	515.35	84.01
Ethylene	66000.00	66000.00	66000.00	8397.41	19000.00	38602.59	13676.95	24925.63	538.98	33.24
Ethane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.37	0.13
Propylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.55	0.00
Propane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stream	R1	R2	HM1	HM2	R1-W	F2V-W	R2-W	F1V-W	VAPRETRN	
Temperature (ºF)	-143.69	-29.56	85	85	85	85	85	85	72.6	
Pressure (psia)	21	250	550	200	21	21	250	252	21	
Mass Flow (lbs/hr)	24925.63	19000.00	1702.22	120.00	24925.63	13676.95	19000.00	8397.41	66000.00	
Component Mass Flow (lb/hr)										
Hydrogen	0.00	0.00	603.97	2.61	0.00	0.00	0.00	0.00	0.00	
Methane	0.00	0.00	515.35	84.01	0.00	0.00	0.00	0.00	0.00	
Ethylene	24925.63	19000.00	538.98	33.24	24925.63	13676.95	19000.00	8397.41	66000.00	
Ethane	0.00	0.00	35.37	0.13	0.00	0.00	0.00	0.00	0.00	
Propylene	0.00	0.00	8.55	0.00	0.00	0.00	0.00	0.00	0.00	
Propane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Butane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Section 7. Assembly of Database

i. Thermophysical Properties

The primary chemicals in this process are ethylene, propylene, hydrogen, methane, butane, styrene, and ethylbenzene. Styrene and ethylbenzene are heavily present in the pyrolytic oil, while the rest are present in the process streams. Note that the C4+ species in the process streams were approximated to have the same thermophysical properties of butane. The thermophysical properties of all chemicals were found from the *NIST Chemistry WebBook* and *Engineering Toolbox*. Wherever exact figures were not available, approximate figure were interpolated or extrapolated. Data from these sources were used to approximate heats of combustion, average specific heat capacities, enthalpies, saturation conditions and more.

ii. Raw Materials

The raw materials in this process are the plastic shards that purchased. The price of the raw materials is $261/MT, where 70MT/day is being fed to the process. The safety information for 2, 4, 5, 6 plastics can be found in Appendix C.

Section 8. Process Description

i. Process Description: Overall Process

The process is comprised of four major processing events: upstream processing of the plastic waste, pyrolysis of the clean plastic waste, steam cracking of the pyrolysis gas product, and a separation train to isolate the desired products and hydrocarbon byproducts that can be used as fuel within the process. Assuming a daily feed of 70 MT, the feed to the process is 6,417 lbs/hr of mixed plastic waste, which is 12% polystyrene, 23% high-density polyethylene, 28% low-density polyethylene, and 37% polypropylene. Upstream processing includes shredding, washing, and drying the plastic waste, then feeding the clean, shredded plastic into an extrusion screw to melt the plastic into liquid. Pyrolysis takes place in a rotary kiln, and produces solid char, liquid oil, and a gas product. The pyrolysis gas is refined in a steam cracker unit, then processed to be sent through a separation train. The separation train involves four distillation columns and yields seven product streams, two of which are the desired ethylene and propylene monomer feedstock products.

ii. Section 000: Upstream Processing

The feed to the process is a mixture of HDPE, LDPE, PP, and PS flakes which arrive in either railcars or shipping containers depending on availability. The composition is described in section 5.6 Feed Assumptions, as is the variability of units in this section. The plastic shards are loaded via a 55 ft bucket elevator into two storage silos, each with a capacity of 10500 ft^3 to account for 3 days' worth of feedstock. The silos are kept at standard temperature and pressure. The silos are designed to hold a combined 6 days' worth of feedstock due to variability in waste availability, and the likelihood that the feed comes from multiple sources. This is enough to prevent a halt in downstream production should waste availability become a bottleneck. A screw conveyor is used to transport the plastic shards to a second bucket elevator of 16ft, from which the shards are emptied into the hopper of the extrusion screw in section 100. The feed rate is assumed a constant 6430 lb/hr through the conveyor and second bucket elevator, as the subsequent sections operate continuously.

iii. Section 100: Rotary Kiln Pyrolysis

The clean and pelletized plastic waste is fed into a standard polymer processing extrusion screw. The screw is used simply as an efficient way to melt the plastic, making use of the friction generated by the screw to reduce heating requirements. The screw relies on an 820 hp motor, as well as scattered heaters, to melt the plastic shards primarily due to friction and pressure created by the screw. The plastic leaves the screw at 482 ^{0}F, at which point it should be entirely liquid. Although the rotary kiln is capable of processing solid plastic waste, the screw is used to ensure efficient heat transfer throughout the kiln. The melted plastic is fed immediately to the rotary kiln, where it is heated inside an inner pressurized chamber of the rotary kiln which is 42 feet long and 2.8 feet in diameter. The plastic waste remains in the kiln for 47.5 minutes, as determined by the angle of the kiln. The plastic is expected to be heated at a rate of 68^0 F/min to 1112^0 F for 17.5 minutes, and then maintained at that temperature for 30 minutes. A screw conveyor moves the plastic and liquid waste through the kiln at a constant speed of 0.0147 ft/sec. The gas buildup in the container ultimately reaches a pressure of 5 bar, in which case a pressure cap allows the gas to pass downstream. This pressure is expected to carry the gas product to the steam cracker at a continuous rate of 5161 lb/hr.

At the far end of the kiln, 1265 lb/hr of a char and oil mix is sent to a small cylindrical vessel where the liquid oil and solid char are separated. This vessel is designed to be 60% full, with a carbon steel grating designed as a baffle positioned in the center. There is one outlet on each side of the baffle, one which removes pure liquid oil at a rate of 1003 lb/hr, and another which removes an oil and char slurry at a rate of 262 lb/hr, assuming that 15% of the oil product remains in the slurry. Two small MOYNO pumps made of temperature may be necessary to continue to drive the wet char and liquid products from the pressure vessel. However, in this process, it is assumed that the pressure of the liquid is enough to force both streams to flow. Regular cleaning of the grating may be necessary. A pilot plant will be used to determine the need for pumps, cleaning, and the flow rates of both streams. The slurry is sent to a storage tank where it is sold for its heating value and for potential applications in road covering for a price equal to that of transporting it. The pure liquid product is split three ways, with 306 lb/hr sent to the heating section of the rotary kiln, 19.9 lb/hr sent to the constant temperature section of the kiln, and 674 lb/hr sent to a storage tank for sale as a fuel oil. The pyrolytic oil is sold for half the price of NAPTHA oil, given its similar heat of combustion but unknown chemical composition.

To the heating section of the rotary kiln, a blower pumps in 2474 lb/hr of air at 77 ^{0}F and 14.7 psia, while a second blower pumps 161 lb/hr of air to the heating section. In both combustion chambers surrounding the rotary kiln, complete combustion is assumed due to the excess air added. The pressures in each chamber are maintained at 36.8 psia, at which point a pressure cap permits the gas to exit. The combustion gases exit the combustion chambers at 36.8 psia and 1292 ^{0}F where there are sold for their heating value at a price assumed equal to that of pumping the gas.

iv. *Section 200: Steam Cracking, Quenching, and Compression*

a. *Steam Cracker Unit*

The steam cracker pyrolyzes gas feed into smaller carbon chains with a dominant selectivity of propylene and ethylene. Typical feedstocks are naphtha, liquefied petroleum gas, or ethane; though in this design, a mixture of light gases ranging from hydrogen to C4+ species are the feed. Note that the C4+ species are estimated as butane for calculation purposes and the feed was not burned in the presence of oxygen. A stream of 5,163 lb/hr of light gases flows from the rotary kiln to the steam cracker at a pressure of 75 psia and a temperature of 1,112°F. This stream is also diluted with low pressure steam upon entering the cracker. Steam to hydrocarbon ratios depends on the feedstock. For ethane cracking the ratio ranges from 0.25 – 0.35 and for naphtha cracking they range from 0.4-0.5. A ratio 0.4 was chosen and the flowrate of steam for the process is 2,066 lb/hr [8.1].

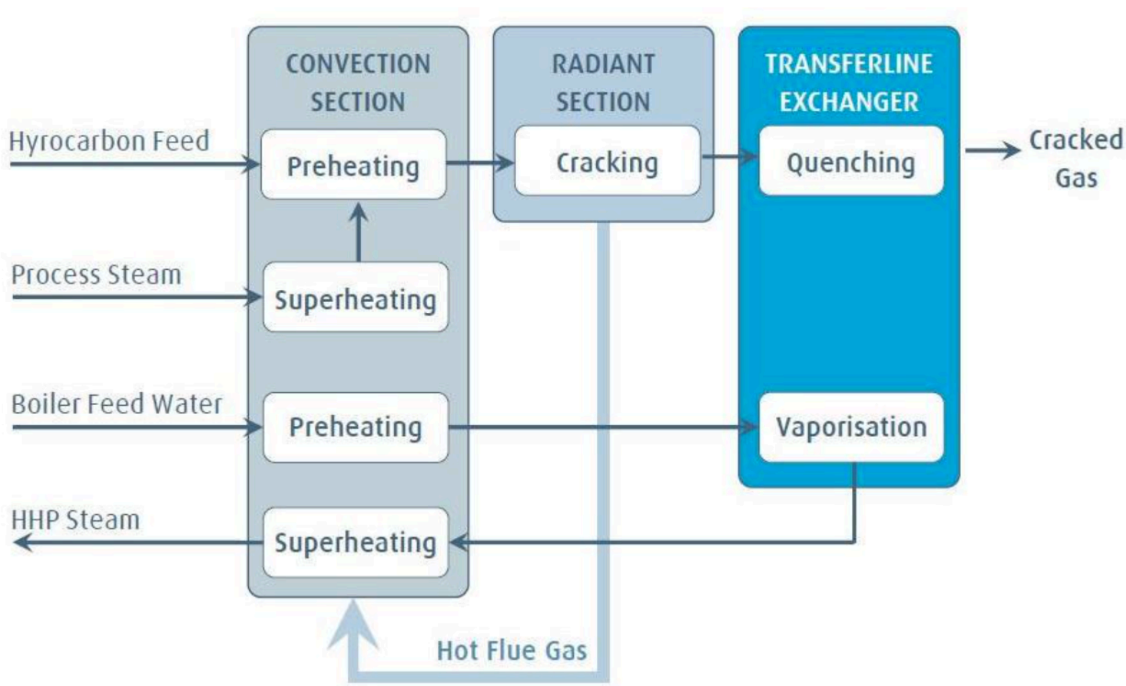

Figure 8.1: Conventional energy recovery systems in steam cracker [8.2]

Note that steam crackers are split into three sections: convection, radiant, and the transfer line exchanger (TLE). Though the convection section traditionally performs the functions shown in figure 8.1, for the design in this report, only the heating of the process steam will occur. It is intended that the light gas feed enters the furnace close to the radiant section. Note that the process steam is a recycled stream from the split water stream exiting the Quench Tower (QT-201). The process steam will be preheated from 120°F to 1,112°F, the crossover temperature with the light gas feed.

The cracking of the light gases occurs in the radiant section. The fuel requirement for the radiant section is determined from heat needed to preheat the process steam, the sensible heat needed to raise the temperature of the light gas and steam mixture, and the heat needed to crack the gas into the products. Fuel for the radiant section is drawn from the storage tanks used to store recovered hydrocarbons and from pyrolytic oil product from the rotary kiln. 10% excess air was assumed for complete combustion and hot flue gases will flow up into through the convection section into the stack. See Appendix A for detailed calculations.

Highly reactive cracked gas must be rapidly quenched below critical temperature within very short amounts of time. TLEs can have residence times as short as milliseconds [8.3]. After passing through the furnace the cracked gas flows in a co-current tube in tube TLE with bfw as a coolant. 4,163 lb/hr of bfw is pumped to 470 psi upon before entering the TLE. The bfw undergoes a phase change, reaches its saturation temperature of 460°F, is then superheated to 600°F, and is finally sold as high-pressure steam.

b. Transfer Line Exchanger

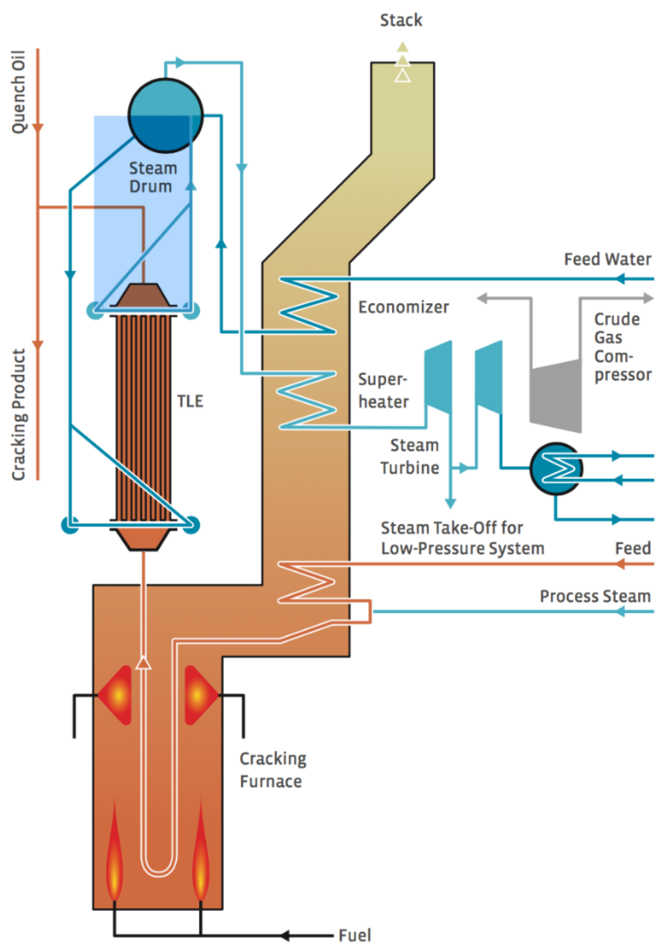

Figure 7.2: Conventional Furnace and TLE Layout [8.3]

A consideration that was not implemented was that the convection section of the steam cracker could be used to reheat low pressure steam used in the reboilers of distillation columns and elsewhere in the plant. At current capacity, there is still an abundance of fuel recovered from separation processes that can be burned. Just as seen in figure 8.2, systems that incorporate TLEs often have steam drums and economizers to regulate the production of steam. An economizer and steam drum are not needed in this design because heat integration will not be conducted with the steam, and because we assumed that all of the bfw fed to the TLE will undergo a phase change to become steam. The bfw stream would also need to be tested for alkalinity levels, else it will increase fouling in the TLE. Finally more accurate fuel requirements could have been made if calculations incorporated the rate of heat transfer through the Inconel™ tubes in the cracker furnace. Given the time constraints and peculiarity of the semester, we elected to not proceed with these options.

c. Spray Quench Tower

The quench tower is the second stage of rapid cooling of the cracked gas stream. Cracked gas and process steam will exit the TLE at 752°F and at pressure of 78 psia. 185,480 lb/hr of 90°F cooling water will be used to cool the cracked gas to 100°F. It is assumed that the cracked gases will not contaminate the contacting water because the gases will not condense in the tower conditions. Given the outlet temperature of the gas is below the critical point of water, we assume perfect mixing which results in all of the process steam mixed in with the cracked gas condensing out. Thus the cracked gas exiting the quench tower (CG-1) will have no water in it. We recognize that is not the case in a real tower, but we did not have enough information to carry out necessary calculations.

187,546 lb/hr of water flows through the bottom of the tower and 2066 lb/hr, an amount equivalent to the process steam originally fed, is split and is recycled to steam cracker to be reheated. The rest of the water is then cooled in a heat exchanger, and finally is recycled to the quench tower to be reused for cooling the cracked gas stream. Note that an inventory of water would be supplied to the tower upon startup and the stream will then recycle through.

d. Molecular Sieve Dryer & Caustic Tower (Omitted Units)

Most ethylene plants will have a caustic tower to remove acidic and sulfuric wastes from the gases. Since we are not recycling PET, PVC, or #7 plastics, we assume that no halides, acids, or sulfur derivatives will enter the process. A molecular sieve dryer would be used to remove water from the cracked gas stream, but it is not needed given the perfect mixing assumption. If molecular sieves were required, two or more sieves would need to be operating parallel. By placing the molecular sieves in parallel, one or more will be operating at regular capacity, while the other units are being cleaned. It should be noted that the dehydration rates of the sieves will not be linear because the mass transfer driving force weakens as more water is absorbed. That being said, molecular sieves should not operate to 100% capacity.

e. Compression and Cooling

Before they can be separated, the cracked gases must be compressed significantly so that their boiling points can increase to feasible temperature for separations purposes. Based on the Section 200 PFD, stream CG-1 enters at 60 psia and stream CG-9 exits at 559.5 psia. Between each compressor there is a cooler unit because the temperature of streams increases after compression, and it takes less work to compress a cooler gas than a hotter one. Four compressors were chosen due to its frequency in the models that we studied, but it would be reasonable to optimize this since the output of this plant is much less than any large ethylene plant.

v. Section 300: Separations

After the cracked gas is quenched and compressed, it is sent to the separations section to isolate the two desired products, ethylene and propylene, as well as the waste hydrocarbons that will be used as fuel for the pyrolysis and steam cracking units. A vapor stream consisting of hydrogen, ethylene, propylene, and other light hydrocarbons is sent into this section at a rate of 5,164 lbs/hr at 142.5°F and 555 psia. Our project goal was to produce ethylene and propylene monomer feedstock. We were able to produce 99.0% pure ethylene product, which qualifies as polymer grade, and 95.7% pure propylene, which qualifies as chemical grade. Each of the four separation processes includes a column, condenser, reflux drum, and kettle-reboiler, as well as pumps for the reflux streams.

a. Demethanizer Tray Tower

The first distillation column, referred to as the demethanizer, is a tray tower that has vapor and liquid distillates and a liquid bottoms product. The vaporous stream from the steam cracking section is fed above stage six at a rate of 5,164 lbs/hr, a temperature of 142.5°F, and pressure of 555 psia. A partial condenser with a vapor/liquid split of 0.448 is used to obtain two distillate products, and a kettle-reboiler is used for the bottoms product. The tray tower has a total of 17 stages, including the partial condenser with a reflux ratio of 5, 15 sieve-trays, and a kettle-reboiler.

The vapor distillate from the demethanizer is a mix of mainly hydrogen, methane, and ethylene at -131.2°F and 550 psia. These extreme operating conditions are necessary to achieve the desired split, because all of the components fed to the column are quite light and volatile. Ideally, only the most volatile components, hydrogen and methane, should come off the top of this column. Unfortunately, this would require an even lower temperature of about -230°F. The amount of energy and refrigerant required to obtain this temperature in the condenser would be an enormous expense and was not a feasible option for the purpose of this project. Instead, we allowed 539 lbs/hr of ethylene to exit the condenser with the vapor distillate, which brought the temperature up to a more reasonable -131.2°F. This means that a significant portion of our ethylene product could not be recovered, but we do not count this as a total loss; the vapor distillate from the demethanizer is fed to the refrigeration system, then used as fuel for other process units in the process. A pressure of 550 psia was selected to increase the temperature of the vapor distillate as well.

The liquid distillate from the demethanizer, referred to as the ethylene recovery stream, exits as a liquid at a rate of 2,098 lbs/hr and is composed mostly of methane, ethylene, ethane, and propylene. It has a temperature of -131.2°F and a pressure of 550 psia. This stream contains all of the ethylene that will be eventually recovered as product, but it also has residual methane that was not removed in the demethanizer column. This stream is fed directly to a second tray column, which we refer to as the deethanizer column. It also has propylene, which must be removed and sent to the depropanizer so that it can be recovered as product. The liquid bottoms product exits at a rate of 1,364 lbs/hr and is composed mostly of propylene, propane, and butane.

b. Deethanizer Tray Tower

The deethanizer column has a total of 45 stages, including a partial condenser with all-vapor distillate, and a reflux ratio of 25; 43 sieve-trays; and a kettle reboiler. The ethylene recovery stream from the demethanizer is fed above stage 29 of the tray tower at 2,098 lbs/hr, and there are three streams that exit the tower: the all-vapor distillate at 120 lbs/hr, which is composed mostly of methane and ethylene; a liquid C2 side-stream that exits from stage 9 at 1,500 lbs/hr and is composed mostly of ethylene and ethane; and a bottoms product at 475 lbs/hr that is composed mostly of ethane, propylene, propane, and butane. The vapor distillate, which leaves the condenser at -129.8°F and 200 psia, is sent to the refrigeration system before being used as fuel for the steam cracking unit. The C2 side-stream exits at -44.2 °F and 203.56 psia, and is fed to the third column, which we refer to as the C2-Splitter. Finally, the bottoms product exits at 57.5°F and 207.2 psia and is fed with the demethanizer bottoms product to the final column, the depropanizer.

A reflux ratio of 25 might sound alarmingly high, but it only corresponds to a reflux rate of 3,000 lbs/hr. This is because the vapor distillate flowrate is quite small compared to the other streams in the process (120 lbs/hr compared to thousands of lbs/hr). If the flowrate of the vapor distillate was on that order, the condenser duty would be unreasonably high at that reflux ratio and temperature, but because the distillate flowrate is low, it is feasible for the purposes of this project. For a higher flowrate on the order of 1,200 lbs, the reflux rate would have been 30,000 lbs/hr and would have over-burdened the condenser. In addition, the original design called for a reflux ratio of 50; 25 seems even more reasonable set against 50!

Because the deethanizer condenser must also operate at an extremely low temperature, it was necessary to allow some ethylene to exit the tower with the vapor distillate. This allowed for a more reasonable condenser temperature. A liquid side-stream was selected rather than using a partial-vapor condenser because it yielded better results. Stage 9 was selected to remove the side-stream because this was determined to be the stage at which the ethylene composition was highest; since the side stream is the stream from which the ultimate ethylene product is removed, it is preferable to have the highest ethylene content possible so that the most ethylene possible is recovered overall.

c. C2-Splitter Tray Tower

The liquid side-stream from the deethanizer is fed above stage 12 of the C2-Splitter, the third tray tower. This feed has a flowrate of 1,500 lbs/hr, a temperature of -44.2°F, and a pressure of 300 psia. A feed pump is used to bring the feed stream to an appropriate pressure; the feed stream exits the deethanizer at 204 psia but needs to be increased to 300 psia to be fed to the C2-Splitter, which operated at 290 psia. The C2-Splitter has 25 stages, including a partial condenser with all vapor distillate and a reflux ratio of 10, 23 sieve-trays, and a kettle reboiler. A vapor distillate of 99.0% pure ethylene product exits the condenser and is sent to be used as feedstock via gas pipelines at a flowrate of 1,410 lbs/hr, a temperature of -20.6°F, and a pressure of 290 psia. A liquid bottoms product that is 94.5% ethane exits the reboiler and is sent to a tank to be stored and used as fuel for other units in the process at a flowrate of 90 lbs/hr, a temperature of 17.3°F, and 296 psia.

d. Depropanizer Tray Tower

The bottoms products from both the demethanizer and deethanizer are sent to the final tray tower, which we refer to as the depropanizer. The depropanizer has 42 stages, including a partial condenser with all vapor distillate and a reflux ratio of 42, 40 sieve-trays, and a kettle-reboiler. Both feed streams are fed above stage 23. Three streams exit the C2 splitter: a vapor distillate of 96 lbs/hr at -11.3°F and 150 psia, a liquid propylene side stream or 1250 lbs/hr at 69.2°F and 154 psia exiting at stage 15, and a liquid bottoms product of 495 lbs/hr at 149.1°F and 157 psia.

Similar to the deethanizer, the reflux ratio may seem alarming at first glance. However, the same logic that applies to the deethanizer applies here, too: the reflux rate is 4,032 lbs/hr, which does not cause the condenser duty to be too high. For a larger distillate rate of, say, 1,000 lbs/hr, a reflux ratio on the order of 1 might be selected instead (say, for example, 3); this would correspond to a reflux rate of 3,000 lbs/hr. So, while the reflux ratio does seem quite high, when considering the reflux *rate* (which is what dictates the condenser duty), it makes sense how such a large reflux could be sustained without causing extreme financial burden.

vi. Section 400: Refrigeration System

The condensers of the columns in the separation section of this process operate at extremely low temperatures. To achieve these low temperatures, a refrigeration system is used. Since the vapor distillates of each column come off at very cold temperatures, too, a plate-fin heat exchanger is used in the refrigeration system to "recover" this cold. Apart from the cold distillates that pass through the plate-fin exchanger, the refrigeration system is a closed loop. Ethylene refrigerant enters the refrigeration system at a flowrate of 66,000 lbs/hr, a temperature of 85°F, and a pressure of 30 psia. The refrigerant passes through a condenser, where it reaches 2000 psia, before being fed to the plate-fin exchanger. The refrigerant is then flashed in a flash drum, and vapor product is sent immediately back to the plate-fin exchanger. The liquid product is split into two streams. The first stream, which has a flowrate of 19,000 lbs/hr, a temperature of -29°F, and a pressure of 252 psia, is sent to the condensers of the C2-Splitter and the depropanizer column, whose operating temperatures are -30°F and -10°F, respectively. The second stream is sent to a second flash drum, and the vapor product is sent immediately back to the plate-fin exchanger. The liquid product flows to the demethanizer and deethanizer column at a flowrate of 24,925 lbs/hr, a temperature of -143.7°F, and a pressure of 21 psia.

The condenser duties for the demethanizer and deethanizer columns are -5MM BTU/hr and -605,000 BTU/hr, respectively. A refrigerant flowrate of 24,925 lbs/hr at the given conditions satisfies the condenser duties of both columns. Then, because the vapor distillates of these columns are so cold (-131°F and -129°F, respectively), they are sent back to the plate-fin exchanger to help cool the refrigerant coming from the condenser. The condenser duties for the C2-Splitter and depropanizer columns are -1.97MM BTU/hr and -702,000 BTU/hr, respectively. A refrigerant flowrate of 19,000 lbs/hr at the given conditions satisfies the condenser duties of both columns.

A plate-fin exchanger was selected as the heat exchanger for this process because it is capable of handling many streams at a given time. As the name implies, a plate-fin exchanger is made of several plates with fins to facilitate heat transfer. In this plate-fin exchanger, several corrugated stainless-steel plates, which serve as the fins, are stacked between flat stainless-steel plates that separate the different streams passing through the exchanger. This plate-fin exchanger handles fourteen streams in total: seven inlet streams, and seven outlet streams. The duty of the plate-fin exchanger is -5.2MM BTU/hr.

For startup, since there would not be cold streams from the column condensers to cool the ethylene after compression, refrigerant is required to supply this duty. This refrigerant can be used to supply the initial -5.2MM BTU/hr of cooling duty in the plate-fin exchanger. Refrigerant at -30°F can be purchased for $4/ton-day. One ton-day is equivalent to 12,000 BTU, so 433 ton-days are required. This corresponds to $1,732/hr worth of -30°F refrigerant for startup. Startup is assumed to take 5 hours—this corresponds to a total cost of $8,660.

Section 9. Energy Balance and Utility Requirements

i. Section 100: Rotary Kiln Pyrolysis

The rotary kiln unit is self-sustaining in energy requirement and does not need fuel oil for the heating requirement of the plastic waste. The extrusion screw demands significant energy input with an 820 hp motor. Use of extra pyrolytic oil or steam from downstream in the process was considered, but polymer extrusion screws are not designed for this type of heating. Alternatives to make use of the oil and steam for melting were considered, but due to the nature of solid processing and need for a continuous feed, the extrusion screw is most appealing.

ii. Section 200: Steam Cracking, Quenching, and Compression

Utilities required in the overall process are cooling water, low pressure steam, boiler feed water, refrigerant, and electricity. In the steam cracking portion, boiler feed water and cooling water are used to rapidly quench hot gases, as well as other streams in that section. In the separation train, low pressure steam will be used to heat the reboilers and refrigerant will be used in the refrigeration cycle. Electricity will be needed for pumps, compressors, and blowers throughout the plant. The following tables will provide information on the quantity of utilities being used in the plant.

a. Fuel Requirements

Fuel to fire the steam cracker furnace will come from recovered fuel from the separation processes and from the pyrolytic oil product from the rotary kiln. The fuel requirement of the steam cracker was completely satisfied with the recycled fuel streams. The fuel that was burned in the steam cracker consists of hydrogen, methane, ethane, ethylene, propane, propylene, butane, and pyrolytic oil which is mostly styrene. The duty of the steam cracker is 34.24 MM BTU/hr.

Table 9.2 Fuel Specifications

Compound	Amount (lb/hr)	% of Furnace Duty	LHV (BTU/lb)
Hydrogen	607	27.6	51,628
Methane	599	47.7	21,433
Ethene	582	32.3	20,525

Table 9.1: Utility requirements for units in Section 200

Utility	Description	Total Power	Quantity Requirement
Chilled Water**	HX-202: Cools down to 90°F	5.61 MM BTU/hr	80,112 lb/hr
Cooling Water	HX-203: Cools down to 224°F	544,300 BTU/hr	11,198 lb/hr
Cooling Water	HX-204: Cools to 226‡F	545,899 BTU/hr	11,224 lb/hr
Cooling Water	HX-205: Cools to 192°F	523,772 BTU/hr	9,073 lb/hr
Cooling Water	HX-206: Cools to 143°F	500,378 BTU/hr	10,627 lb/hr
Cooling Water*	Quench Tower: Cools to 100°F	5.62 MM BTU/hr	185,480 lb/hr
Boiler Feed Water	HX-201: Cools to 752°F	3.68 MM BTU/hr	4,163 lb/hr
Low Pressure Steam*	Process Steam to be mixed with light gas	N/A	2,066 lb/hr
High Pressure Steam	Vaporization of BFW. Sold as credit.	N/A	242,180 lb/hr
Electricity	B-201: Blows CRACKED GAS to compressors	34 kW	5,161 lb/hr
Electricity	P-201: Increases pressure of BFW to 450 psi	134 kW	242,180 lb/hr
Electricity	P-202: Pumps spray water recycle to top of Quench Tower	5 kW	185,480 lb/hr
Electricity	P-203: Pumps process steam to convection section	0.16 kW	2,066 lb/hr

*The utilities are only required for start-up purposes.

** The utility comes from unit E-303.

iii. Section 300: Separations

a. Energy Balance

In the separations part of the process, there are four distillation columns, which each have a condenser with cooling duty. The cooling for each condenser is achieved by streams from the refrigeration cycle. The following table shows the energy balance on each condenser:

Table 9.3: Energy balance on the condensers of the distillation columns.

	Demethanizer	Deethanizer	C2-Splitter	Depropanizer
Condenser Duty (BTU/hr)	-5,002,048	-603,978	-1,68,988	-702,413
Condenser Temp (°F)	-131.2	-129.8	-20.6	-11.2
Coolant Source	DM-DE	DM-DE	C2-DEPROP-REF	C2-DEPROP-REF
Flowrate of coolant	24,926	24,926	19,000	19,000

Each column in the separation part of the process also has a reboiler with a heating duty. Low-pressure steam provides heat to the demethanizer, deethanizer, and depropanizer reboilers, while 60°F cooling water provides heat to the C2-Splitter reboiler. The following table shows the energy balance on each reboiler:

Table 9.4: Energy balance on the reboilers of the distillation columns.

	Demethanizer	Deethanizer	C2-Splitter	Depropanizer
Reboiler Heat Duty (BTU/hr)	3,599,122	749,516	2,194,171.38	597,034
Reboiler Temp (°F)	205.2	57.5	17.3	149.1
Heat source	50 psig steam	50 psig steam	60°F cooling water	50 psig steam
Flowrate of heat source (lbs/hr)	3,946.4	821.84	109,709	655

Calculations to determine the required flowrate of heat source are found in the following section.

b. Utilities

The reboilers of the tray towers each require a utility to provide heat. For the demethanizer, deethanizer, and depropanizer, low-pressure steam is used to provide heating. For the C2-Splitter, cooling water is used to provide heat, because the temperature of the bottoms product is very low at 17°F. The following table summarizes the steam requirements for each column based on the heat duty of the reboiler:

Table 9.5: Low-pressure steam requirements for the reboilers of the demethanizer, deethanizer, and depropanizer columns

	Demethanizer	Deethanizer	Depropanizer
Reboiler Heat Duty (BTU/hr)	3,599,122	749,516	597,034
Reboiler Temp (°F)	205.2	57.5	149.1
Steam Pressure required (psig):	50	50	50
Latent Heat (BTU/hr):	912	912	912
Required Flowrate (lbs/hr):	3,946.4	821.84	654.64

Because the reboiler temperatures are all relatively low, low-pressure steam is required to provide heating.

Interestingly, the reboiler of the C2-Splitter requires cooling water to provide heating. This is because the bottoms product of the C2-Splitter is 17°F. A stream in the range of 60-70°F would be ideal to provide heating, but something hotter would run the risk of causing film boiling. Thus, cooling water was selected as the utility, since it is in that temperature range. The reboiler heat duty is 2,2MM BTU/hr. Since the specific heat capacity of water at that temperature is 1 BTU/lb-°F, the flowrate of cooling water needed is 109,800 lbs/hr.

Whence the cooling water has passed through the reboiler, it will be at a temperature of 40°F, qualifying it as chilled water. Some of this chilled water will be sent to the quench tower at a rate of 80,200 lbs/hr, and the remaining 29,600 lbs/hr will be sold as chilled water.

In addition to the condensers and reboilers in the separations part of the process, there are five pumps that are powered by electricity—four pumps that are used for the reflux streams for each column, and one pump that is used for the feed to the C2-Splitter. The following table summarizes the utilities required for each pump:

Table 9.6: Utilities requirements for pumps in the separations part of the process

	Demethanizer Reflux	Deethanizer Reflux	C2-Splitter Reflux	Depropanizer Reflux	C2 Feed
Net Work	0.297 hp	0.5194 hp	0.3695 hp	0.5079 hp	1.22 hp
Electricity Requirement	0.2215 kW	0.3876 kW	0.2731 kW	0.3791 kW	0.914 kW

iv. Section 400: Refrigeration System

a. Energy Balance

The refrigeration cycle consists of a compressor, plate-fin exchanger, and two flash vessels, each of which has an associated cooling or heat duty with it. This part of the process has immense energy and utility requirements, and contributes significantly to the annual cost

The compressor compresses 66,000 lbs/hr of ethylene refrigerant from 85 psia to 2,000 psia. Electricity is used to achieve this pressure change; 4,333 kW are needed to power this unit.

The plate-fin exchanger involves 14 streams. It recovers the cold from the vapor distillates from the demethanizer and deethanizer columns, as well as the vapor streams from both flash vessels, and cools the ethylene refrigerant before it goes to the flash vessels. The plate-fin exchanger has a cooling duty of -22.3MM BTU/hr.

The first flash vessel reduces the temperature of the refrigerant from -1.2°F to -29.06°F by dropping the pressure 2000 psia to 252 psia. The Joule-Thompson effect is responsible for this temperature drop. The gas is allowed to expand through a throttle. During this expansion, there is no change in energy, which means that the duty of the flash vessel is zero. This is because for all non-ideal gasses (i.e. gasses other than hydrogen or helium), enthalpy is a function of temperature, so if the enthalpy remains constant, the temperature will, too. Since the gas in the process is *not* an ideal gas (especially since it is at an extremely high pressure), constant enthalpy does not equal constant temperature, so the temperature of the gas drops significantly when the gas is throttled.

The second flash vessel reduces the temperature of the refrigerant from -29.06°F to -143.7°F by dropping the pressure from 252 psia to 21 psia. Similar to the first flash vessel, the Joule-Thompson effect is responsible for the temperature drop. There is no change in energy during throttling, so the duty of the flash vessel is zero.

b. *Utilities:*

In the refrigeration cycle, the compressor uses 5,810 hp of work and requires 4,333 kW of electricity for power. This amount of electricity is one of the costliest utilities in the entire process, with over $2.5MM being spent annually. For comparison, the second costliest compressor is in the compression cascade of the steam cracking process, and costs $162,000 per year.

For startup, 433 ton-day, or $8,660 worth, of -30°F refrigerant are needed for the plate-fin exchanger; afterwards, the cold streams from the demethanizer and deethanizer condensers are used for cooling.

Section 10. Equipment List and Unit Descriptions

i. Section 000: Upstream Processing

Storage Silos

Unit ID: T-001; T-002	Temperature: 77^{o}F
Type: Solid Storage Bin	Pressure: 14.7 psia
Material: Carbon Steel	Diameter: 16.5 ft
Costing: Table 12.1	Height: 49.5 ft
	Calculation: Appendix A

The function of T-001 and T-002 is to store three days' worth of feed shard each to prevent production halt. The temperature and pressure are not regulated and are therefore said to be atmospheric. The volume of each silo is 10500 ft^3, found using an assumed shard density of 58.9 lb/ft^3 and a 25% void fraction due to packing. An aspect ratio of 3, common for storage vessels, is used. Each silo has an upper cylindrical section and lower conical section. The purchase cost of each silo is $45,707. No specification sheet is included.

Bucket Elevators

Unit ID: E-001; E-003	Width: 12 in
Type: Solid Handling Equipment	Height: 55 ft (001); 16 ft (002)
Costing: Table 12.1	Work: 0.626 hp (001); 0.206 hp (002)
	Calculation: Appendix A

The function of the bucket elevators is to move plastic shard from the transport units to storage silos, and again from the screw conveyor to the extrusion screw. The units consist of chains of buckets, 12 inches in width and 1.5 feet apart, which move the plastic shard vertically. Due to the nature of the plastic shards, there is no concern that waste sticks to the bucket, and high speeds are usable, but 150 ft/sec is estimated. The speed and bucket volume more importantly depend on unit availability for purchase. The 55-foot bucket elevator has a power requirement of .626 hp, and the 16-foot elevator 0.206 hp, which account for both the mass flow rate and vertical distance travelled. The purchase cost of the 55-foot elevator is $23,534, and that of the 16-foot elevator is $11,642. No specification sheet is included.

Screw Conveyor

Unit ID: E-002	Length: 40 ft
Type: Solid Handling Equipment	Work: 0.958 hp
Feed Rate: 81.9 ft^3/hr	
Costing: Table 12.1	Calculation: Appendix A

The screw conveyor is selected for transport of shards due to its ability to regulate volumetric flow capacity and handle particles of small size. The feed rate of the screw is 81.9 ft^3/hr, which roughly correlates to a 6-inch diameter 50 rpm conveyor. The length of transport is estimated as 40 feet, which is to account for the space occupied by the silos. The power requirement is 0.958 hp, which assumes no elevation change. The purchase cost of the feeder is $2,883. No specification sheet is included.

ii. Section 100: Rotary Kiln Pyrolysis

Rotary Kiln

Unit ID:	R-101	Temperature:	1112^{0}F
Type:	Reactor	Pressure:	73.5 psia
Material:	Carbon Steel, Alumina Oxide Refractory	Length:	42 ft
Spec Sheet:	Section 11	Diameter:	2.8 ft inner, 7.74 ft outer
Costing:	Table 12.1	Calculations:	Appendix A

The rotary kiln is the first of two cracking units in the process. It degrades the molten plastic waste to a short-chain hydrocarbon gas and a pyrolytic oil product, with the presence of some char. The rotary kiln is considered as two concentric pressure vessels. The inner vessel is 2.8 ft diameter, and feed molten plastic continuously at 6430 lb/hr. The plastic is moved through the inner chamber at a constant rate of 0.0147 ft/s as governed by a carbon steel screw conveyor. The inner chamber is maintained at 73.5 psia, at which point a pressure cap, fitted to not rotate with the kiln, permits gaseous product to exit from the highest point in the kiln. The molten plastic is heated first in the kiln over a length of 15.5 ft a rate of 68^0F/min to reach 1112^0F. The plastic is then held at a that temperature for the remaining 26.5 ft. The gaseous product is said to form at a constant rate in the kiln. Over the entire length of the chamber, the energy demand to heat and maintain the plastic temperature is 3.66 x 10^6 BTU/hr. The inner chamber is made from a 0.25-inch-thick layer of Carbon Steel, which is the thickness as estimated for the pressure vessel, surrounded by 8.4 inches of alumina oxide refractory, which is selected due to its high thermal conductivity, strength, and ability to be exposed to temperatures up to 3000 ^{0}F. A thermal conductivity of 10.4 BTU/h ft ^{0}F is used to estimate the wall thickness to achieve a desired ΔT. Due to the thickness of the refractory layer, the temperatures which carbon steel is exposed to should not cause any deformation of the shell.

There are two chambers outside the alumina oxide refractory, which are separated by a refractory wall, which are used for combustion. Both chambers are operated at 36.8 psia and 2732 ^{0}F. The feed rate to each chamber of pyrolytic oil and air is dependent on the energy demands of specific section, assuming 40% thermal efficiency. Not-rotating pressure caps are again used to remove the gaseous product. The combustion chamber is 6 inches, with burners located primarily beneath the inner shell to concentrate heat near the molten plastic.

The outermost layer of the rotary kiln is 14.4 inches of alumina oxide refractory covered with 0.25 inches of carbon steel for structural support. This layer should prevent the exposed surface from exceeding 200 ^{0}F for safety concerns. The reactor is set up at a 1.1^0 incline from the horizontal. Due to the complex nature of cracking reactions and unknown intermediates, the reactor was not modeled in Aspen except for energy balance purposes.

The electricity demands are estimated as 80 kW to power the rotary kiln, per online estimates, accounting for both the rotation of the vessel at nearly 2 rpm and the screw conveyor. The costing is roughly estimated as summing two horizontal pressure vessels, giving a purchase cost of $167,171.

Extrusion Screw

Unit ID:	E-101	Temperature:	482^0F
Type:	Solid Handling Equipment	Costing:	Table 12.1
Work:	820 hp	Calculations:	Appendix A

The extrusion screw is purchased directly from a third-party seller. A twin-screw extruder is likely necessary due to the high mass flow rate. The molten plastic is said to be heated from room temperature to 482^0F, which is 50^0F greater than the melting point of polystyrene (which has the highest melting point of all three types of plastic involved). The work required is 820 hp, and per online estimate the purchase cost is $500,000. No specification sheet is included, but a brochure for a potential module is included in the Appendix.

Blower 1

Unit ID:	B-101	Temperature:	77^0F
Type:	Centrifugal	Pressure:	36.8 psia
Material:	Aluminum	Work:	26.1 hp
Spec Sheet:	Section 11		
Costing:	Table 12.1	Calculations:	Appendix A

The blower adds air to the first combustion chamber which supplies heat to raise the temperature of the plastic waste in the rotary kiln. It raises incoming pressure from atmospheric to 36.8 psia. The temperature is said to be atmospheric at both the inlet and outlet of the blower, and thus the blower is made from aluminum. It requires a net work of 26.1 hp due to 88% efficiency. The flow rate through the blower is 539 ft^3/min, and the purchase cost is an estimated $8,820.

Blower 2

Unit ID:	B-102	Temperature:	77^0F
Type:	Centrifugal	Pressure:	36.8 psia
Material:	Aluminum	Work:	3.8 hp
Spec Sheet:	Section 11		
Costing:	Table 12.1	Calculations:	Appendix A

Nearly identical to B 101, except a lesser volumetric flow rate of 35.1 ft^3/min is used, creating a work requirement of 3.8 hp and efficiency of 83%. The purchase cost is an estimated $8,820.

Solid Liquid Splitter

Unit ID:	E - 102	Temperature:	1112^0F
Type:	Storage Tank	Pressure:	73.5 psia
Material:	Carbon Steel	Length:	10.5 ft
Spec Sheet:	Section 11	Diameter:	2.09 ft
Costing:	Table 12.1	Calculations:	Appendix A

This unit is largely hypothetical, and a pilot plant would be necessary to determine the feasibility. To remove the char from the liquid oil as best as possible, the solid/liquid slurry flows into the vessel at 1265 lb/hr, driven by the pressure in the rotary kiln. The size is approximated considering how much oil/char mixture enters the unit over the course of one residence time (47.5 minutes), and an assumed aspect ratio of 5. The splitter is said to be 60% full, and still at a pressure of 73.5 psia. There is a fine carbon steel mesh, which is oriented as a baffle, near the center of the vessel. There are two outlets, which have volumetric flow rates of 1003 lb/hr (oil product), and 262 lb/hr (slurry). The ratio of outlet sizes of the tank reflects the ratio of flow rates. The pressure is assumed to be sufficient to drive the operation of this unit. It is possible that MOYNO pumps, capable of low flow rates and sustaining very high temperatures, would be required to drive the flow. The purchase cost is an estimated $10,628.

Oil Storage Tank

Unit ID:	T - 101	Temperature:	1112^0F
Type:	Storage Tank	Pressure:	14.7 psia
Material:	Carbon Steel	Height:	21.9 ft
Spec Sheet:	Section 11	Diameter:	7.3 ft
Costing:	Table 12.1	Calculations:	Appendix A (sample)

Given a flow rate of oil for sale of 674 lb/hr, an assumed density of 58.3 lb/ft^3, and a desired capacity to store 6 days of product, a total storage volume of 925 ft^3 is required. Using an assumed aspect ratio of 3, the dimensions of this unit are 7.3 ft diameter and 21.9 ft height. The oil product enters the storage tank at high temperature of 1112 ^{0}F and pressure of 73.5 psia, but no effort is made to maintain these conditions. The tank is designed as a conical roof storage vessel, and a nitrogen blanket is used to maintain safe oxygen concentration. The purchase cost is an estimated $24,728.

Slurry Storage Tank

Unit ID:	T - 101	Temperature:	1112^0F
Type:	Storage Tank	Pressure:	14.7 psia
Material:	Carbon Steel	Height:	19.5 ft
Spec Sheet:	Section 11	Diameter:	6.5 ft
Costing:	Table 12.1	Calculations:	Appendix A (sample)

The same approach is taken here to modeling the tank as the pyrolytic oil storage tank, although the inlet flow is now 262 lb/hr. The purchase cost is an estimated $3404.

iii. Section 200: Steam Cracking, Quenching, and Compression

Steam Cracker

Unit ID:	F-201	Temperature:	1472°F
Type:	Pyrolysis Furnace	Pressure:	43.5 psia
Material:	Carbon Steel & Inconel™	Area:	
Spec Sheet:	Section 11	Duty:	34.24MM BTU/hr
Costing Data:	Section 12	Calculations:	Appendix A

The steam cracker takes paraffinic light gas mixed with steam and dehydrates, or cracks, the compounds into ethylene and propylene. The steam cracker also preheats 242,480 lb/hr of boiler water and 2,066 lb/hr of water to be used as process steam. Fuel to fire the steam cracker comes from oil product from the rotary kiln, and recovered fuel from separation processes. The steam cracker has severity of 0.66, which corresponds to a 1 second residence time in the furnace. The steam cracker has a convective section and radiation section. The exact dimensions of the steam cracker were not calculated, but a private consultant provided costing data based on its ethylene output.

Transfer Line Exchanger

Unit ID:	HX-201	Temperature (Hot Fluid):	1472°F
Type:	Tube in Tube Heat Exchanger	Coolant Flow Rate:	4,163 lb/hr
Material:	Carbon Steel	Area:	
Spec Sheet:	Section 11	Duty:	3.68MM BTU/hr
Costing Data:	Section 12	Calculations:	Appendix A

The transfer line heat exchanger rapidly quenches the cracked gas to prevent more propagation reactions from occurring. The transfer line exchanger is modeled after a BORSIG tunnelflow exchanger. Hot gases will flow through the tubes and boiler water will flow concurrently in the annulus of the tubes. Within the TLE, the boiler water will undergo a phase change and become high pressure steam.

Quench Tower Heat Exchanger

Unit ID:	HX-202	Temperature (Hot Fluid):	120°F
Type:	Shell and Tube	Coolant Flow rate:	80,112 lb/hr
Material:	Carbon Steel	Area:	772.4ft^2
Spec Sheet:	Section 11	Duty:	5.61MM BTU/hr
Costing Data:	Section 12	Calculations:	Appendix A

The heat exchanger in the quench tower recycle system is a shell and tube heat exchanger, and it cools the recycle spray water stream from 120°F back down to 90°F. The chiled water experiences a temperature change from 40°F to 105°F. Flow in the heat exchanger is countercurrent.

Intercooler 1

Unit ID:	HX-203	Temperature (Hot Fluid):	324°F
Type:	Shell and Tube	Coolant Flow Rate:	11,198 lb/hr
Material:	Carbon Steel	Area:	47.26 ft^2
Spec Sheet:	Section 11	Duty:	544,300 BTU/hr
Costing Data:	Section 12	Calculations:	Appendix A

The intercooler is modeled as a shell and tube heat exchanger on ASPEN. It cools the stream after COMP-1 from 324°F to 224°F. The gas stream experiences a temperature drop of 100°F in all four intercoolers. The temperature change in the cooling water is 80°F to 120°F, which is the same for all four units. Inter-stage coolers are needed because it takes less work to compress a cooler gas than a hotter gas.

Intercooler 2

Unit ID:	HX-204	Temperature (Hot Fluid):	327°F
Type:	Shell and Tube	Coolant Flow Rate:	11,224 lb/hr
Material:	Carbon Steel	Area:	46.6 ft^2
Spec Sheet:	Section 11	Duty:	545,899 BTU/hr
Costing Data:	Section 12	Calculations:	Appendix A

Intercooler 3

Unit ID:	HX-205	Temperature (Hot Fluid):	292°F
Type:	Shell and Tube	Coolant Flow Rate:	11,061 lb/hr
Material:	Carbon Steel	Area:	54.8 ft^2
Spec Sheet:	Section 11	Duty:	523,771 BTU/hr
Costing Data:	Section 12	Calculations:	Appendix A

Intercooler 4

Unit ID:	HX-206	Temperature (Hot Fluid):	239°F
Type:	Shell and Tube	Coolant Flow Rate:	10,627 lb/hr
Material:	Carbon Steel	Area:	84.3 ft^2
Spec Sheet:	Section 11	Duty:	544,825 BTU/hr
Costing Data:	Section 12	Calculations:	Appendix A

Compressor 1

Unit ID:	C-201	Outlet Temperature:	324°F
Type:	Centrifugal	Outlet Pressure:	159 psia
Material:	Carbon Steel	Net Work:	369 hp
Spec Sheet:	Section 11	Efficiency:	0.81
Costing Data:	Section 12	Calculations:	Appendix A

Compressor 1 is a centrifugal compressor used to increase the pressure of the cracked gas before it undergoes separation. The gas enters the series of compressors at 60 psia and leaves at 559.5 psia. The pressure of this stream needs to be increased so that the boiling point of certain compounds will shift to temperature to a more feasible one for separation. All compressors in Section 200 were modeled on ASPEN. The isentropic efficiency was assumed to be 0.81.

Compressor 2

Unit ID:	C-202	Outlet Temperature:	327°F
Type:	Centrifugal	Outlet Pressure:	274 psia
Material:	Carbon Steel	Net Work:	175 hp
Spec Sheet:	Section 11	Efficiency:	0.81
Costing Data:	Section 12	Calculations:	Appendix A

Compressor 3

Unit ID:	C-203	Outlet Temperature:	292°F
Type:	Reciprocating	Outlet Pressure:	389 psia
Material:	Carbon Steel	Net Work:	111 hp
Spec Sheet:	Section 11	Efficiency:	0.81
Costing Data:	Section 12	Calculations:	Appendix A

Compressor 4

Unit ID:	C-204	Outlet Temperature:	239°F
Type:	Reciprocating	Outlet Pressure:	560 psia
Material:	Carbon Steel	Net Work:	110 hp
Spec Sheet:	Section 11	Efficiency:	0.81
Costing Data:	Section 12	Calculations:	Appendix A

Blower 1

Unit ID:	B-201	Outlet Temperature:	129°F
Type:	Centrifugal	Outlet Pressure:	73 psia
Material:	Aluminum	Net Work:	234 hp
Spec Sheet:	Section 11	Efficiency:	1
Costing Data:	Section 12	Calculations:	Appendix A

Blower 1 is used to move fuel gases from the storage tanks to the steam cracker furnace. It was modeled as an isentropic compressor on ASPEN. It is sized to move 606 lb/hr of hydrogen, 599 lb/hr of methane, and 582 lb/hr of ethylene.

iv. Section 300: Separations

<u>Tray Towers</u>

Demethanizer Column

Unit ID:	D-301	Temperature:	142.5°F
Type:	Distillation Column	Pressure:	550 psia
Material:	Carbon Steel	Functional height:	42.5 ft
Spec Sheet:	Section 11	Diameter:	5.4 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

The demethanizer separates a significant portion of the hydrogen and methane gas produced in the steam cracking of the pyrolysis gas from the light hydrocarbons and the heavy hydrocarbons. The feed to the demethanizer is 5,164 lbs/hr of cracked gas, which enters the column at 142.5°F and 555 psia.

According to an ASPEN simulation, 12 theoretical stages are needed to achieve the desired separation, with the feed stream entering above stage 4. Assuming a tray efficiency of 0.7, this means that fifteen real stages are needed, with the feed stream entering above the sixth stage. Given eighteen-inch spacing between each tray, a height of 22.5 ft is obtained. One 3-foot manhole at the feed stage and an additional 3-foot manhole every ten trays are included, as well as a 10-foot sump and 4-ft of height at the top of the column, resulting in a functional height of 42.5 ft. Including a skirt height of 15 ft, the total demethanizer height is 57.5 ft. An L/D aspect ratio of 8 was chosen, yielding a diameter of 5.3 ft.

A reflux ratio of 5 is required. The vapor distillate rate is 1,702 lbs/hr, the liquid distillate rate is 2,098 lbs/hr, and the bottoms rate is 1,364 lbs/hr. The selected material of construction is carbon steel. The temperatures of the columns are extremely cold. Carbon steel is the material of construction for many cryogenic units, including cold boxes, which operate at temperatures similar to those in this process. So, carbon steel is an appropriate choice of material for the columns.

The reflux drum for the demethanizer condenser was sized so that fifteen minutes of accumulation would result in the drum being half-full. Given a volumetric reflux rate of 682 cuft/hr, the reflux drum would need to have a volume of 341 cubic feet for fifteen minutes' worth of accumulation to fill half of the drum. Using an L/D aspect ratio of 4 for a horizontal vessel, a length of 36.2 ft and a diameter of 9.05 ft were determined.

The kettle reboiler for the demethanizer column has a heat duty of 3.6MM BTU/hr, as calculated by ASPEN. Low-pressure steam must be supplied at a flowrate of 3,950 lbs/hr.

Deethanizer Column

Unit ID:	D-301	Temperature:	-131.2°F
Type:	Distillation Column	Pressure:	200 psia
Material:	Carbon Steel	Functional height:	84.5 ft
Spec Sheet:	Section 11	Diameter:	8.45 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

The deethanizer results in three outlet streams: a vapor distillate, which contains the remaining hydrogen and methane, as well as some of the ethylene product; a liquid side stream, which contains both ethylene and ethane hydrocarbons; and the bottoms product, which contains all the hydrocarbons heavier than ethane. The feed to the deethanizer is the 2,098 lbs/hr ethylene recovery stream from the demethanizer, which enters the deethanizer at -131.2°F and 550 psia.

According to an ASPEN simulation, 30 theoretical trays are needed to achieve the desired separation, with the feed stream entering above the twentieth stage. Assuming a tray efficiency of 0.7, this means that 43 real stages are needed, with the feed stream entering above the twenty-ninth stage. Given eighteen-inch spacing between each tray, a height of 64.5 ft is obtained. One 3-foot manhole at the feed stage and an additional 3-foot manhole every ten trays are included, as well as a 10-foot sump and 4-ft of height at the top of the column, resulting in a functional height of 84.5 ft. Including a skirt height of 15 ft, the total demethanizer height is 99.5 ft. An L/D aspect ratio of 10 was chosen, yielding a diameter of 8.45 ft.

A reflux ratio of 25 is required. The distillate rate is 120 lbs/hr, the side stream flow rate is 1,500 lbs/hr, and the bottoms rate is 475 lbs/hr. The selected material of construction is carbon steel. The temperatures of the columns are extremely cold. Carbon steel is the material of construction for many cryogenic units, including cold boxes, which operate at temperatures similar to those in this process. So, carbon steel is an appropriate choice of material for the columns.

The reflux drum for the deethanizer condenser was sized so that fifteen minutes of accumulation would result in the drum being half-full. Given a volumetric reflux rate of 107 cuft/hr, the reflux drum would need to have a volume of 53.5 cubic feet for fifteen minutes' worth of accumulation to fill half of the drum. Using an L/D aspect ratio of 3 for a horizontal vessel, a length of 7.6 ft and a diameter of 2.5 ft were determined.

The kettle reboiler for the deethanizer column has a heat duty of 750,000 BTU/hr, as calculated by ASPEN. Low-pressure steam must be supplied at a flowrate of 822 lbs/hr.

As discussed in the process description in Section 8, a reflux ratio of 25 for the deethanizer column might seem alarmingly high at first. The distillate rate of the deethanizer column is only 120 lbs/hr, and the reflux rate is 3,000 lbs/hr. This corresponds to a cooling duty of -604,000 BTU/hr. This duty is far less than that of either the demethanizer or C2-Splitter condensers, whose reflux ratios are much smaller (5 and 10, respectively) but who have much higher cooling duties on the order of MM BTU/hr because their distillate flowrates (and, thus, their reflux rates) are much higher, even at a relatively low reflux ratio. Clearly, the value of the reflux ratio is not the best indicator of condenser duty, but rather the reflux flowrate is.

C2 Feed Pump

Unit ID:	P-301	Temperature:	-41.3°F
Type:	Centrifugal	Outlet Pressure:	300 psia
Material:	Carbon Steel	Net Work:	1.22 hp
Spec Sheet:	Section 11	Head:	477.0 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

The side stream that exits the deethanizer to enter the C2-Splitter has a pressure of 204 psia. This is below the operating pressure of the C2-Splitter (290 psia), so the stream must be sent to a pump to increase the pressure. A head of 477.0 ft and net work of 1.22 hp were calculated using ASPEN.

C2-Splitter

Unit ID:	D-303	Temperature:	-44.2°F
Type:	Distillation Column	Pressure:	290 psia
Material:	Carbon Steel	Functional height:	54.5 ft
Spec Sheet:	Section 11	Diameter:	5.45 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

The C2-Splitter separates the recovered ethylene from the other components that exit the deethanizer column in the side-stream. The feed to the C2-Splitter is 1,500 lbs/hr, which enters the column at -44.2°F and 300 psia after passing through the C2 feed pump.

According to an ASPEN simulation, 23 theoretical trays are needed to achieve the desired separation, with the feed stream entering above the twelfth stage. In the industry, C2-Splitters typically have an efficiency of 1.0 or even greater than 1. Assuming a tray efficiency of 1, this means that 23 real stages are needed, with the feed stream entering above the twelfth stage. Given eighteen-inch spacing between each tray, a height of 34.5 ft is obtained. One 3-foot manhole at the feed stage and an additional 3-foot manhole every ten trays are included, as well as a 10-foot sump and 4-ft of height at the top of the column, resulting in a functional height of 54.5 ft. Including a skirt height of 15 ft, the total demethanizer height is 69.5 ft. An L/D aspect ratio of 10 was chosen, yielding a diameter of 5.45 ft.

A reflux ratio of 10 is required. The distillate rate is 1,410 lbs/hr, and the bottoms rate is 90 lbs/hr. The selected material of construction is carbon steel. The temperatures of the columns are extremely cold. Carbon steel is the material of construction for many cryogenic units, including cold boxes, which operate at temperatures similar to those in this process. So, carbon steel is an appropriate choice of material for the columns.

The reflux drum for the C2-Splitter condenser was sized so that fifteen minutes of accumulation would result in the drum being half-full. Given a volumetric reflux rate of 567 cuft/hr, the reflux drum would need to have a volume of 283 cubic feet for fifteen minutes' worth of accumulation to fill half of the drum. Using an L/D aspect ratio of 3 for a horizontal vessel, a length of 30 ft and a diameter of 7.5 ft were determined.

The kettle reboiler for the C2-Splitter column has a heat duty of 2.2MM BTU/hr, as calculated by ASPEN. The bottoms product of the C2-Splitter exits at 17°F, meaning that a heat source around 60°F would be ideal. Cooling water at a temperature of 60°F must be supplied at a flowrate of 110,000 lbs/hr. This cooling water exits the reboiler at a temperature of 40°F, meaning that it can be used as chilled water in other parts of the plant, and the remaining water can be sold as chilled water (which is worth more than the cooling water that would need to be purchased to provide heat to the kettle reboiler).

Depropanizer

Unit ID:	D-304	Temperature:	103.3°F
Type:	Distillation Column	Pressure:	150 psia
Material:	Carbon Steel	Functional height:	80.0 ft
Spec Sheet:	Section 11	Diameter:	8.0 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

The depropanizer separates the bottoms products from both the demethanizer and deethanizer into three products: a C2-fuel, the 95.7% pure propylene product, and impure butane to be used as fuel. The feed to the depropanizer is 1,839 lbs/hr, which enters the column at -103.3°F and a pressure of 150.0 psia.

According to an ASPEN simulation, 28 theoretical trays are needed to achieve the desired separation, with the feed stream entering above stage 16. Assuming a tray efficiency of 0.7, this means that 40 real stages are needed, with the feed stream entering above stage 23. Given eighteen-inch spacing between each tray, a height of 60.0 ft is obtained. One 3-foot manhole at the feed stage and an additional 3-foot manhole every ten trays are included, as well as a 10-foot sump and 4-ft of height at the top of the column, resulting in a functional height of 80.0 ft. Including a skirt height of 15 ft, the total demethanizer height is 95.0 ft. An L/D aspect ratio of 10 was chosen, yielding a diameter of 8.0 ft.

A reflux ratio of 42 is required. The distillate rate is 96 lbs/hr, the propylene-product side stream flowrate is 1,250 lbs/hr, and the bottoms rate is 90 lbs/hr. The selected material of construction is carbon steel. The temperatures of the columns are extremely cold. Carbon steel is the material of construction for many cryogenic units, including cold boxes, which operate at temperatures similar to those in this process. So, carbon steel is an appropriate choice of material for the columns.

The reflux drum for the depropanizer condenser was sized so that fifteen minutes of accumulation would result in the drum being half-full. Given a volumetric reflux rate of 145.5 cuft/hr, the reflux drum would need to have a volume of 72.7 cubic feet for fifteen minutes' worth of accumulation to fill half of the drum. Using an L/D aspect ratio of 3 for a horizontal vessel, a length of 10.3 ft and a diameter of 3.4 ft were determined.

The kettle reboiler for the depropanizer column has a heat duty of 600,000 BTU/hr, as calculated by ASPEN. Low-pressure steam must be supplied at a flowrate of 655 lbs/hr.

As discussed in the process description in Section 8, a reflux ratio of 42 for the depropanizer column might seem alarmingly high at first. However, the same reasoning that is applied to the deethanizer column condenser is relevant here. The distillate rate for the depropanizer column is only 96 lbs/hr, and the reflux rate is only 4,032 lbs/hr. This corresponds to a condenser cooling duty of -597,000 BTU/hr. This duty is far less than that of either the demethanizer or C2-Splitter condensers, whose reflux ratios are much smaller (5 and 10, respectively) but who have much higher cooling duties on the order of MM BTU/hr because their distillate flowrates (and, thus, their reflux rates) are much higher, even at a relatively low reflux ratio. Clearly, the value of the reflux ratio is not the best indicator of condenser duty, but rather the reflux flowrate is.

Reflux Pumps

The reflux stream that exits the condenser of each column must be pumped back to the top of the demethanizer tower. The pump is not at the same elevation as the condenser; in chemical plants, pumps are placed on the ground to allow for easy access for maintenance. As the reflux stream flows downward to the pump, it gains some pressure. Then, the pump increases the pressure of the stream further to allow it to travel back up to the top of the condenser for reflux. The head of each pump was calculated using the methods discussed in Appendix A.

Demethanizer Reflux Pump

Unit ID:	RP-301	Temperature:	-131.2°F
Type:	Centrifugal	Outlet Pressure:	579 psia
Material:	Carbon Steel	Net Work:	0.297 hp
Spec Sheet:	Section 11	Head:	116 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

Deethanizer Reflux Pump

Unit ID:	RP-302	Temperature:	-129.8°F
Type:	Centrifugal	Outlet Pressure:	247 psia
Material:	Carbon Steel	Net Work:	0.5194 hp
Spec Sheet:	Section 11	Head:	203 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

C2-Splitter Reflux Pump

Unit ID:	RP-303	Temperature:	-20.6°F
Type:	Centrifugal	Outlet Pressure:	325 psia
Material:	Carbon Steel	Net Work:	0.3659 hp
Spec Sheet:	Section 11	Head:	143 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

Depropanizer Reflux Pump

Unit ID:	RP-304	Temperature:	-11.3°F
Type:	Centrifugal	Outlet Pressure:	297 psia
Material:	Carbon Steel	Net Work:	0.5079 hp
Spec Sheet:	Section 11	Head:	199 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

Storage Tanks

Storage tanks are needed for both monomer products, ethylene and propylene, and the hydrocarbon streams that will be stored and used as fuel. Since the products of the steam cracking process are all light hydrocarbons that are gasses as atmospheric pressure, each tank is designed to hold one hour's worth of product. For the ethylene and propylene products, the streams will then be sold and transported to plants via pipeline to be used as monomer feedstock. One hour of storage is needed in case the purchasing plant needs to shut down; in that case, there would be a buffer to allow for gas to stop flowing to the shut-down plant while still being produced until our plant could be properly shut down, too. In such an event, the rotary kiln would be shut off upstream, and the product would accumulate in the storage vessel; one hour is sufficient time for the remaining material in the process to reach the storage vessel, so one hour's worth of storage is needed to contain that material.

Ethylene Product Storage Tank

Unit ID:	T-301	Temperature:	70°F
Type:	Storage Tank	Pressure:	30 psia
Material:	Carbon Steel	Height:	59.0 ft
Spec Sheet:	Section 11	Diameter:	19.7 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

The 99.0% pure ethylene product exits the C2-Splitter at a flowrate of 1410 lbs/hr at -20.6°F and 290 psia. At the conditions in the tank, ethylene has a density of 0.079 lbs/cuft, and 134,193 gallons of storage are needed for one hour's worth of product. This gas is then transported to the purchasing plant via gas pipeline.

Propylene Product Storage Tank

Unit ID:	T-303	Temperature:	70°F
Type:	Storage Tank	Pressure:	30 psia
Material:	Carbon Steel	Height:	59.0 ft
Spec Sheet:	Section 11	Diameter:	19.7 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

The 95.7% pure propylene product exits the depropanizer at a flowrate of 1250 lbs/hr at 70°F and 154 psia. At these conditions, propylene is a liquid. However, at the conditions in the tank, it will be a vapor whose density is 0.118 lb/cuft. This means that 85,704 gallons of storage are needed to hold one hour's worth of propylene product. This propylene is then transported to the purchasing plant to be used as feedstock via gas pipeline.

Fuel Storage Tank

Unit ID:	T-302	Temperature:	70°F
Type:	Storage Tank	Pressure:	30 psia
Material:	Carbon Steel	Height:	77.0 ft
Spec Sheet:	Section 11	Diameter:	25.5 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

Five streams are sent to the fuel storage tank to be stored and used as fuel. One hour's worth of fuel is stored in this tank. Because a mix of several different hydrocarbons are stored, each with a different density at these conditions, a weighted average was calculated to determine the density of the gas in the fuel storage tank (which was 0.0645 lbs/cuft). Any streams that exit the column as a liquid will become vapor at these conditions.

v. Section 400: Refrigeration System

Refrigeration System Compressor

Unit ID:	C-401	Temperature:	85°F
Type:	Compressor	Pressure:	30 psia
Material:	Carbon Steel	Work:	5810 hp
Spec Sheet:	Section 11	Flowrate:	452,497 cuft/hr
Costing Data:	Section 12	Design Calculations:	Appendix A

The compressor in the refrigeration system must compress 66,000 lbs/hr of ethylene refrigerant. The ethylene refrigerant comes into the compressor at a temperature of 85°F and a pressure of 30 psia. The compressor uses electricity as its utility and does 5,810 hp of work. The refrigeration system is a closed cycle; the ethylene is compressed, cooled and flashed, and then it is sent to the appropriate compressors to provide cooling, after which it is sent back through the plate-fin exchanger so that it can return to the start of the cycle.

Flash Vessel 1

Unit ID:	F-401	Temperature:	-29.06°F
Type:	Flash Drum	Pressure:	252 psia
Material:	Carbon Steel	Height:	5.51 ft
Spec Sheet:	Section 11	Diameter:	1.84 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

Flash Vessel 1 is used in the refrigeration cycle to lower the refrigerant temperature so that it can be used in the condensers of the columns in the separation section of the process. 66,000 lbs/hr of refrigerant are fed into Flash Vessel 1 at 4.6°F and 2000 psia. 8,3971 lbs/hr exit the vessel as vapor and are sent back to the plate-fin exchanger. 57,603 lbs/hr of refrigerant exit the vessel as liquid and are split into two streams: the first stream goes directly to the condensers of the C2-Splitter and the depropanizer, and the second stream is sent to the second flash vessel to lower the temperature further.

The Jules-Thompson effect is responsible for the temperature and pressure change experienced by the ethylene refrigerant. For all gases other than hydrogen and helium, a decrease in pressure due to gas expansion reduces gas temperature.

The vessel was modeled as a vertical pressure vessel. Assuming a residence time of 5 minutes, which is a standard residence time for flash vessels, and given a volumetric flowrate of 2,631 cuft/hr through the vessel, this corresponds to a volume of 1,640 gallons. Using an L/D aspect ratio of 3, this also gives a height of 13.6 ft and a diameter of 4.5 ft.

Flash Vessel 2

Unit ID:	F-402	Temperature:	-143.69°F
Type:	Flash Drum	Pressure:	21 psia
Material:	Carbon Steel	Height:	2.06 ft
Spec Sheet:	Section 11	Diameter:	0.69 ft
Costing Data:	Section 12	Design Calculations:	Appendix A

Flash Vessel 2 is used in the refrigeration cycle to further lower the temperature of some of the liquid outlet of the first flash vessel so that it can be used in the condensers of the columns in the separation section of the process. 38,603 lbs/hr of refrigerant are fed into Flash Vessel 2 at -29.06°F and 252 psia. 13,677 lbs/hr exit the vessel as vapor and are sent back to the plate-fin exchanger. 24,926 lbs/hr of refrigerant exit the vessel as liquid and this stream is sent to the separation section of the process to be used in the condensers of the demethanizer and deethanizer columns.

The Jules-Thompson effect is responsible for the temperature and pressure change experienced by the ethylene refrigerant. For all gases other than hydrogen and helium, a decrease in pressure due to gas expansion reduces gas temperature.

The vessel was modeled as a vertical pressure vessel. Assuming a residence time of 5 minutes and given a volumetric flowrate of 1,380 cubic feet per hour through the vessel, this corresponds to a volume of 860 gallons. Using an L/D aspect ratio of 3, this also gives a height of 11.0 ft and a diameter of 3.65 ft.

Plate-Fin Exchanger

Unit ID:	H-401	Temperature:	100°F
Type:	Plate-Fin Exchanger	Pressure:	2000 psia
Material:	Carbon Steel	Area:	6789 sqft
Spec Sheet:	Section 11	Duty:	-4774835.37 BTU/hr
Costing Data:	Section 12	Design Calculations:	Appendix A

This plate-fin exchanger is based on a model by a Stewart-Warner South Wind plate-fin exchanger. Several corrugated stainless-steel sheets are layered between flat stainless-steel sheets. Seven inlet streams and seven outlet streams flow through this heat exchanger, allowing for the refrigerant to be cooled by the cold distillate streams from the separation section of the process. This model of heat exchanger is very efficient at transferring heat, because there are many opportunities for heat transfer among the various inlet and outlet streams. The refrigerant is then sent to the separation process to be used in the condensers of the separation columns. The duty of the plate-fin exchanger is -4.78MM BTU/hr.

Section 11. Specification Sheets

i. Section 100: Rotary Kiln Pyrolysis

Rotary Kiln Reactor

Identification:		Item:	*Reactor*	Date:	*14 April 2020*
		Item No.:	*R-101*		
		No. Required:	*1*	By:	*MCL*
Function:		*Perform Initial Cracking Reactions on Molten Plastic Feedstock*			
Operation:	Continuous				
Materials Handled:					

Stream ID:	**Molten Waste**	**Air Pdt**	**Dirty Oil**	**Oil Feed 1**	**Oil Feed 2**	**Air 1**	**Air 2**	**Hot Air 1**	**Hot Air 2**
Phase	Liquid	Gas	Liquid	Liquid	Liquid	Gas	Gas	Gas	Gas
Temperature (F):	482	1112	1112	1112	1112	77	77	1292	1292
Pressure (psia):		74	74	74	74	37	37	37	37
Mass Flow (lbs/hr):	6430.00	5163.00	1265.00	306.00	20.00	7045.00	459.00	7594.00	692.00
Component Mass Flow((lbs/hr):									
Polyethylene	3291.00	-	-	-	-	-	-		-
Polypropylene	2392.00	-	-	-	-	-	-		-
Polystyrene	746.00	-	-	-	-	-	-		-
Hydrogen	-	37.00	-	-	-	-	-		-
Methane	-	690.00	-	-	-	-	-		-
Ethane	-	547.00	-	-	-	-	-		-
Ethene	-	1024.00	-	-	-	-	-		-
Propane	-	521.00	-	-	-	-	-		-
Propene	-	975.00	-	-	-	-	-		-
Butane	-	1369.00	-	-	-	-	-		-
Toluene	-	-	263.24	68.00	4.00	-	-		-
ethylbenzene	-	-	121.88	32.00	2.00	-	-		-
xylene	-	-	67.67	18.00	1.00	-	-		-
styrene	-	-	487.40	126.00	8.00	-	-		-
a-methyl-styrene	-	-	66.25	17.00	1.00	-	-		-
naphthalene	-	-	97.79	25.00	2.00	-	-		-
methylnaphthalene	-	-	77.00	20.00	1.00	-	-		-
water vapor	-	-	-	-	-	-	-	437.00	216.00
Carbon Dioxide	-	-	-	-	-	-	-	112.00	17.00
air	-	-	-	-	-	7045.00	459.00	7045.00	459.00
Carbon	-	-	84.00	-	-	-	-	-	-

Design Data:	Inner Diameter:	2.8 ft	Material of Construction:	Alumina Oxide Refractory, Carbon Steel
	Outer Diameter:	7.74 ft	Type:	Rotary Kiln Reactor
	Length:	42 ft	Duty:	3664000 BTU/hr
	Rotational Speed:	2 rpm	Residence Time:	47.5 min
	Angle (degrees):	1		
Utilities:			Electricity Requirement: 80 kW	
Comments:			See Section 7 Process Flow Diagram Section 100	

Solid Liquid Splitter

Identification:	Item:	*Type of Item*		Date:	*14 April 2020*
	Item No.:	*E-102*			
	No. Required:	*1*		By:	*MCL*
Function:		*Remove char from pyrolytic oil product*			
Operation:	Continuous				
Materials Handled:			**Feed**	**Outlet 1**	**Outlet 2**
Stream ID:			Dirty Oil	Oil Pdt	Wet Char
Temperature (F):			1112	1112	1112
Pressure (psia):			73.5	73.5	73.5
Mass Flow (lbs/hr):			1265.00	1003.00	262.00
Component Mass Flow((lbs/hr):					
Polyethylene			-	-	-
Polypropylene			-	-	-
Polystyrene			-	-	-
Char			84.00	-	84.00
Styrene			-	-	-
Xylene			-	-	-
Ethylbenzene			-	-	-
Toluene			263.00	224.00	39.00
Naphthalene			122.00	104.00	18.00
Methyl-naphthalene			68.00	57.00	11.00
Alpha-methyl-styrene			487.00	414.00	73.00
Hydrogen			66.00	56.00	10.00
Methane			98.00	83.00	15.00
Ethylene			77.00	65.00	12.00
Ethane			-	-	-
Propylene			-	-	-
Propane			-	-	-
Butane			-	-	-
Oxygen			-	-	-
Carbon Dioxide			-	-	-
Water			-	-	-
Nitrogen			-	-	-
Design Data:	Diameter	2.09 ft			
	Length	10.5 ft			
	Pressure	73.5 psia			
	Temperature	1112 F			
	Material of Construction:	Carbon Steel			
Utilities:					
Comments:		See Section 6 Process Flow Diagram Section 100			

Rotary Kiln Blower - 1

Identification:	Item:	*Blower*	Date:	*14 April 2020*
	Item No.:	*B-101*		
	No. Required:	*1*	By:	*MCL*
Function:	*Blower required for sending air to combustion chamber*			
Operation:	Continuous			
Materials Handled:		**Feed 1**	**Outlet 1**	
Stream ID:		*Air 1*	*Air 1*	
Temperature (F):		77	77	
Pressure (psia):		14.7	36.8	
Mass Flow (lbs/hr):		7045.00	7045.00	
Component Mass Flow((lbs/hr):				
Polyethylene		-	-	
Polypropylene		-	-	
Polystyrene		-	-	
Char		-	-	
Styrene		-	-	
Xylene		-	-	
Ethylbenzene		-	-	
Toluene		-	-	
Naphthalene		-	-	
Methyl-naphthalene		-	-	
Alpha-methyl-styrene		-	-	
Hydrogen		-	-	
Methane		-	-	
Ethylene		-	-	
Ethane		-	-	
Propylene		-	-	
Propane		-	-	
Butane		-	-	
Oxygen		-	-	
Carbon Dioxide		-	-	
Water		-	-	
Nitrogen		-	-	
Air		7045.00	7045.00	
Design Data:	Type	Centrifugal		
	Driver Type	Electric Motor		
	Isentropic Efficiency	1		
	Net Work (HP)	26.1		
	Material of Construction:	Aluminium		
Utilities:	19.5 kW Electricity			
Comments:	See Section 6 Process Flow Diagram Section 100			

Rotary Kiln Blower - 2

Identification:	Item:	*Blower*	Date:	*14 April 2020*
	Item No.:	*B-102*		
	No. Required:	*1*	By:	*MCL*
Function:	*Blower required for sending air to combustion chamber*			
Operation:	Continuous			
Materials Handled:		**Feed 1**	**Outlet 1**	
Stream ID:		*Air 2*	*Air 2*	
Temperature (F):		77	77	
Pressure (psia):		14.7	36.8	
Mass Flow (lbs/hr):		459.00	459.00	
Component Mass Flow((lbs/hr):				
Polyethylene		-	-	
Polypropylene		-	-	
Polystyrene		-	-	
Char		-	-	
Styrene		-	-	
Xylene		-	-	
Ethylbenzene		-	-	
Toluene		-	-	
Naphthalene		-	-	
Methyl-naphthalene		-	-	
Alpha-methyl-styrene		-	-	
Hydrogen		-	-	
Methane		-	-	
Ethylene		-	-	
Ethane		-	-	
Propylene		-	-	
Propane		-	-	
Butane		-	-	
Oxygen		-	-	
Carbon Dioxide		-	-	
Water		-	-	
Nitrogen		-	-	
Air		459.00	459.00	
Design Data:	Type	Centrifugal		
	Driver Type	Electric Motor		
	Isentropic Efficiency	1		
	Net Work (HP)	3.8 hp		
	Material of Construction:	Aluminium		
Utilities:	2.83 kW Electricity			
Comments:	See Section 6 Process Flow Diagram Section 100			

Pyrolytic Oil Storage Tank

Identification:	Item:	*Tank*		Date:	*14 April 2020*
	Item No.:	*T-101*			
	No. Required:	*1*		By:	*MCL*
Function:		*Store six days' worth of pyrolytic oil product*			
Operation:	Continuous				
Materials Handled:					**Feed**
Stream ID:					Pyrolytic Oil Product
Temperature (F):					1112
Pressure (psia):					73.5
Mass Flow (lbs/hr):					674.00
Component Mass Flow((lbs/hr)					
Polyethylene					-
Polypropylene					-
Polystyrene					-
Char					-
Styrene					-
Xylene					-
Ethylbenzene					-
Toluene					150.00
Naphthalene					70.00
Methyl-naphthalene					39.00
Alpha-methyl-styrene					279.00
Hydrogen					38.00
Methane					56.00
Ethylene					44.00
Ethane					-
Propylene					
Propane					-
Butane					-
Oxygen					-
Carbon Dioxide					-
Water					-
Nitrogen					-
Design Data:		Amount stored:	6 days		
		Inside Diamter:	7.3 ft		
		Functional Height:	21.9 ft		
		Material of Construction:	Carbon Steel		
		Pressure:	14.7 psia		
		Total Storage Volume:	6920 gallons		
Utilities:					
Comments:		See Section 6 Process Flow Diagram Section 100			

Slurry Storage Tank

Identification:	Item:	*Tank*		Date:	*14 April 2020*
	Item No.:	*T-102*			
	No. Required:	*1*		By:	*MCL*
Function:		*Store six days worth of oil and char slurry*			
Operation:	Continuous				
Materials Handled:					**Feed**
Stream ID:					Propylene Product
Temperature (F):					1112
Pressure (psia):					73.5
Mass Flow (lbs/hr):					262.00
Component Mass Flow((lbs/hr)					
Polyethylene					-
Polypropylene					-
Polystyrene					-
Char					84.00
Styrene					-
Xylene					-
Ethylbenzene					-
Toluene					39.00
Naphthalene					18.00
Methyl-naphthalene					10.00
Alpha-methyl-styrene					72.00
Hydrogen					10.00
Methane					14.00
Ethylene					11.00
Ethane					-
Propylene					-
Propane					-
Butane					-
Oxygen					-
Carbon Dioxide					-
Water					-
Nitrogen					-
Design Data:		Amount stored:	6 days		
		Inside Diamter:	6.5 ft		
		Functional Height:	19.5 ft		
		Material of Construction:	Carbon Steel		
		Pressure:	14.7 psia		
		Total Storage Volume:	460 gallons		
Utilities:					
Comments:		See Section 6 Process Flow Diagram Section 100			

ii. Section 200: Steam Cracking, Quenching, and Compression

Steam Cracker					
Identification:	Item:	*Steam Cracker*		Date:	*14 April 2020*
	Item No.:	*F-201*			
	No. Required:	*1*		By:	*[POA]*
Function:		*Cracks light gas from rotary kiln into smaller carbon chains.*			
Operation:	Continuous				
Materials Handled:			**Feed 1**	**Feed 2**	**Outlet 1**
Stream ID:			*LG-1*	*PS-1*	*LG-2*
Temperature (F):			1112	120	1472
Pressure (psia):			75	50	450
Mass Flow (lbs/hr):			5,157.00	2,066.00	7,229.00
Component Mass Flow((lbs/hr):					
Polyethylene			-	-	-
Polypropylene			-	-	-
Polystyrene			-	-	-
Char			-	-	-
Styrene			-	-	-
Xylene			-	-	-
Ethylbenzene			-	-	-
Toluene			-	-	-
Naphthalene			-	-	-
Methyl-naphthalene			-	-	-
Alpha-methyl-styrene			-	-	-
Hydrogen			36.00	-	606.00
Methane			690.00	-	606.00
Ethylene			1024.00	-	1978.00
Ethane			547.00	-	219.00
Propylene			975.00	-	1287.00
Propane			521.00	-	58.00
Butane			1364.00	-	409.00
Oxygen			-	-	-
Carbon Dioxide			6.00	-	-
Water			-	2,066.00	2,066.00
Nitrogen			-	-	-
Design Data:	Operating Pressure (psia):	43.5			
	Material of Construction:	Inconel			
Utilities:					
Comments:		See Section 6 Process Flow Diagram Section 200			

Transfer Line Exchanger

Identification:	Item:	*Heat Exchanger*		Date:	*14 April 2020*
	Item No.:	*HX-201*			
	No. Required:	*1*		By:	*[POA]*
Function:	*s heat exchanger rapidly quenches the cracked gas and produces high pressure saturated ste*				
Operation:	Continuous				
Materials Handled:		**Feed 1**	**Feed 2**	**Outlet 1**	**Outlet 2**
Stream ID:		*LG-2*	*BW-2*	*CG-0*	*BW-3*
Temperature (F):		1112	212	752	600
Pressure (psia):		67	470	60	450
Mass Flow (lbs/hr):		7,229.00	4,163.00	7,229.00	4,163.00
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		606.00	-	606.00	-
Methane		606.00	-	606.00	-
Ethylene		1978.00	-	1978.00	-
Ethane		219.00	-	219.00	-
Propylene		1287.00	-	1287.00	-
Propane		58.00	-	58.00	-
Butane		409.00	-	409.00	-
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		2,066.00	4,163.00	2,066.00	4,163.00
Nitrogen		-	-	-	-
Design Data:	Number of Tubes:	20			
	Number of Passes:	2			
	Tube Length (ft):	20			
	Tube Diameter (in):	1.6			
	Exchanger Area (ft^2):				
	Material of Construction:	Carbon Steel			
Utilities:		BOILER FEED WATER			
Comments:		Modeled as a Tunnelflow Transfer Line Exchanger			

Spray Quench Tower

Identification:	Item:	*Quench Tower*		Date:	*14 April 2020*
	Item No.:	*QT-201*			
	No. Required:	*1*		By:	*[POA]*
Function:	*This tower is used to quickly quench the cracked gases.*				
Operation:	Continuous				
Materials Handled:		**Feed 1**	**Feed 2**	**Outlet 1**	**Outlet 2**
Stream ID:		*CG-0*	*SW-3*	*CG-1*	*SW-0*
Temperature (F):		752	90	100	120
Pressure (psia):		78	25	70	14.7
Mass Flow (lbs/hr):		5,163	185,480	5,163	187,546
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		606.00	-	606.00	-
Methane		606.00	-	606.00	-
Ethylene		1978.00	-	1978.00	-
Ethane		219.00	-	219.00	-
Propylene		1287.00	-	1287.00	-
Propane		58.00	-	58.00	-
Butane		409.00	-	409.00	-
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		2066.00	185,480.00	-	187,546.00
Nitrogen		-	-	-	-
Design Data:	Tower Diameter (ft):	3.5			
	Crossection (ft^2)	9.6			
	Height (ft):	8			
	Operating Pressure (psia)	50			
	Weight (lbs):	37,773			
	Material of Construction:	Carbon Steel			
Utilities:					
Comments:	See Section 6 Process Flow Diagram Section 200				

Compressor - 1

Identification:	Item:	*Compressor*	Date:	*14 April 2020*
	Item No.:	*C-201*		
	No. Required:	*1*	By:	*[POA]*
Function:		*Compresses gas stream in preparation for separation processes.*		
Operation:	Continuous			
Materials Handled:			**Feed 1**	**Outlet 1**
Stream ID:			*CG-1*	*CG-2*
Temperature (F):			100	324
Pressure (psia):			60	159
Mass Flow (lbs/hr):			5,163.00	5,163.00
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			606.00	606.00
Methane			606.00	606.00
Ethylene			1978.00	1978.00
Ethane			219.00	219.00
Propylene			1287.00	1287.00
Propane			58.00	58.00
Butane			409.00	409.00
Oxygen			-	-
Carbon Dioxide			-	-
Water			-	-
Nitrogen			-	-
Design Data:	Type	Centrifugal		
	Driver Type	Electric Motor		
	Efficiency	0.81		
	Driver Power (HP)	368.95		
	Material of Construction:	Carbon Steel		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

Compressor - 2

Identification:	Item:	*Compressor*	Date:	*14 April 2020*
	Item No.:	*C-202*		
	No. Required:	*1*	By:	*[POA]*
Function:	*Compresses gas stream in preparation for separation processes.*			
Operation:	Continuous			
Materials Handled:			**Feed 1**	**Outlet 1**
Stream ID:			*CG-3*	*CG-4*
Temperature (F):			224.3	327
Pressure (psia):			159	274
Mass Flow (lbs/hr):			5,163	5,163
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			*606*	*606*
Methane			*606*	*606*
Ethylene			*1,978*	*1,978*
Ethane			*219*	*219*
Propylene			*1,287*	*1,287*
Propane			*58*	*58*
Butane			*409*	*409*
Oxygen			-	-
Carbon Dioxide			-	-
Water			-	-
Nitrogen			-	-
Design Data:	Type	Reciprocating		
	Driver Type	Electric Motor		
	Efficiency	0.81		
	Driver Power (HP)	174.58		
	Material of Construction:	Carbon Steel		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

Compressor - 3				
Identification:	Item:	*Compressor*	Date:	*14 April 2020*
	Item No.:	*C-203*		
	No. Required:	*1*	By:	*[POA]*
Function:	*Compresses gas stream in preparation for separation processes.*			
Operation:	Continuous			
Materials Handled:			**Feed 1**	**Outlet 1**
Stream ID:			*CG-5*	*CG-6*
Temperature (F):			227	292
Pressure (psia):			274	389
Mass Flow (lbs/hr):			5163.00	5163.00
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			606.00	606.00
Methane			606.00	606.00
Ethylene			1978.00	1978.00
Ethane			219.00	219.00
Propylene			1287.00	1287.00
Propane			58.00	58.00
Butane			409.00	409.00
Oxygen			-	-
Carbon Dioxide			-	-
Water			-	-
Nitrogen			-	-
Design Data:	Type	Reciprocating		
	Driver Type	Electric Motor		
	Efficiency	0.81		
	Driver Power (HP)	110.68		
	Material of Construction:	Carbon Steel		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

Compressor - 4

Identification:	Item:	*Compressor*	Date:	*14 April 2020*
	Item No.:	*C-204*		
	No. Required:	*1*	By:	*[POA]*
Function:		*Compresses gas stream in preparation for separation processes.*		
Operation:	Continuous			
Materials Handled:			**Feed 1**	**Outlet 1**
Stream ID:			*CG-7*	*CG-8*
Temperature (F):			192	258
Pressure (psia):			389	560
Mass Flow (lbs/hr):			5163.00	5163.00
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			606.00	606.00
Methane			606.00	606.00
Ethylene			1978.00	1978.00
Ethane			219.00	219.00
Propylene			1287.00	1287.00
Propane			58.00	58.00
Butane			409.00	409.00
Oxygen			-	-
Carbon Dioxide			-	-
Water			-	-
Nitrogen			-	-
Design Data:	Type	Reciprocating		
	Driver Type	Electric Motor		
	Efficiency	0.81		
	Driver Power (HP)	109.72		
	Material of Construction:	Carbon Steel		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

Spray Water Cooler

Identification:	Item:	*Heat Exchanger*		Date:	*14 April 2020*
	Item No.:	*HX-202*			
	No. Required:	*1*		By:	*[POA]*
Function:	*This heat exchanger rapidly quenches the cracked gas and produces high pressure saturated steam.*				
Operation:	Continuous				
Materials Handled:		**Feed 1**	**Feed 2**	**Outlet 1**	**Outlet 2**
Stream ID:		*SW-1*	*CW-IN (not shown)*	*SW-2*	*CW-OUT (not shown)*
Temperature (F):		120	40	90	105
Pressure (psia):		40	14.7	35	14.7
Mass Flow (lbs/hr):		185480.00	80112.00	185480.00	80112.00
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		-	-	-	-
Methane		-	-	-	-
Ethylene		-	-	-	-
Ethane		-	-	-	-
Propylene		-	-	-	-
Propane		-	-	-	-
Butane		-	-	-	-
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		185480.00	80112.00	185480.00	80112.00
Nitrogen		-	-	-	-
Design Data:	Number of Tubes:	16	U (BTU/ft^2-F-h)	250	
	Number of Passes:	3			
	Tube Length (ft):	20			
	Tube Diameter (in):	3			
	Exchanger Area (ft^2):	772.4			
	Material of Construction:	Carbon Steel			
Utilities:					
Comments:		See Section 6 Process Flow Diagram Section 200			

Intercoolerr - 1

Identification:	Item:	*Heat Exchanger*		Date:	*14 April 2020*
	Item No.:	*HX-203*			
	No. Required:	*1*		By:	*[POA]*
Function:	*This heat exchanger cools hot compressed cracked gas so it takes less work to further compress.*				
Operation:	Continuous				
Materials Handled:		**Feed 1**	**Feed 2**	**Outlet 1**	**Outlet 2**
Stream ID:		*CG-2*	*CW-IN (not shown)*	*CG-3*	*CW-OUT (not shown)*
Temperature (F):		324	80	224	120
Pressure (psia):		159	14.7	159	14.7
Mass Flow (lbs/hr):		5163.00	11198.00	5163.00	11198.00
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		606.00	-	606.00	-
Methane		606.00	-	606.00	-
Ethylene		1978.00	-	1978.00	-
Ethane		219.00	-	219.00	-
Propylene		1287.00	-	1287.00	-
Propane		58.00	-	58.00	-
Butane		409.00	-	409.00	-
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		5163.00	11198.00	5163.00	11198.00
Nitrogen		-	-	-	-
Design Data:	Number of Tubes:	5	U (BTU/ft^2-F-h)	80	
	Number of Passes:	1			
	Tube Length (ft):	20			
	Tube Diameter (in):	2			
	Exchanger Area (ft^2):	47.26			
	Material of Construction:	Carbon Steel			
Utilities:		COOLING WATER			
Comments:		See Section 6 Process Flow Diagram Section 200			

Intercooler - 2					
Identification:	Item:	*Heat Exchanger*		Date:	*14 April 2020*
	Item No.:	*HX-204*			
	No. Required:	*1*		By:	*[POA]*
Function:	*This heat exchanger rapidly quenches the cracked gas and produces high pressure saturated steam.*				
Operation:	Continuous				
Materials Handled:		**Feed 1**	**Feed 2**	**Outlet 1**	**Outlet 2**
Stream ID:		*CG-4*	*CW-IN (not shown)*	*CG-5*	*CW-OUT (not shown)*
Temperature (F):		327	80	292	120
Pressure (psia):		274	14.7	274	14.7
Mass Flow (lbs/hr):		5163.00	11224.00	5163.00	11224.00
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		606.00	-	606.00	-
Methane		606.00	-	606.00	-
Ethylene		1978.00	-	1978.00	-
Ethane		219.00	-	219.00	-
Propylene		1287.00	-	1287.00	-
Propane		58.00	-	58.00	-
Butane		409.00	-	409.00	-
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		5163.00	11224.00	5163.00	11224.00
Nitrogen		-	-	-	-
Design Data:	Number of Tubes:	5	U (BTU/ft^2-F-h)	80	
	Number of Passes:	1			
	Tube Length (ft):	20			
	Tube Diameter (in):	2			
	Exchanger Area (ft^2):	46.6			
	Material of Construction:	Carbon Steel			
Utilities:		COOLING WATER			
Comments:		See Section 6 Process Flow Diagram Section 200			

Intercooler - 3

Identification:	Item:	*Heat Exchanger*		Date:	*14 April 2020*
	Item No.:	*HX-205*			
	No. Required:	*1*		By:	*[POA]*
Function:	*This heat exchanger rapidly quenches the cracked gas and produces high pressure saturated steam.*				
Operation:	Continuous				
Materials Handled:		**Feed 1**	**Feed 2**	**Outlet 1**	**Outlet 2**
Stream ID:		*CG-6*	*CW-IN (not shown)*	*CG-7*	*CW-OUT (not shown)*
Temperature (F):		292	80	192	120
Pressure (psia):		389	14.7	389	14.7
Mass Flow (lbs/hr):		5163.00	11061.00	5163.00	11061.00
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		606.00	-	606.00	-
Methane		606.00	-	606.00	-
Ethylene		1978.00	-	1978.00	-
Ethane		219.00	-	219.00	-
Propylene		1287.00	-	1287.00	-
Propane		58.00	-	58.00	-
Butane		409.00	-	409.00	-
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		5163.00	11061.00	5163.00	11061.00
Nitrogen		-	-	-	-
Design Data:	Number of Tubes:	6	U (BTU/ft^2-F-h)	80	
	Number of Passes:	1			
	Tube Length (ft):	20			
	Tube Diameter (in):	1.75			
	Exchanger Area (ft^2):	54.8			
	Material of Construction:	Carbon Steel			
Utilities:		COOLING WATER			
Comments:		See Section 15 Process Flow Diagram Section 200			

Intercooler - 4

Identification:	Item:	*Heat Exchanger*		Date:	*14 April 2020*
	Item No.:	*HX-206*			
	No. Required:	*1*		By:	*[POA]*
Function:	*This heat exchanger rapidly quenches the cracked gas and produces high pressure saturated steam.*				
Operation:	Continuous				
Materials Handled:		**Feed 1**	**Feed 2**	**Outlet 1**	**Outlet 2**
Stream ID:		*CG-8*	*CW-IN (not shown)*	*CG-9*	*CW-OUT (not shown)*
Temperature (F):		239	80	143	120
Pressure (psia):		559.5	14.7	559.5	14.7
Mass Flow (lbs/hr):		5163.00	10627.00	5163.00	10627.00
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		606.00	-	606.00	-
Methane		606.00	-	606.00	-
Ethylene		1978.00	-	1978.00	-
Ethane		219.00	-	219.00	-
Propylene		1287.00	-	1287.00	-
Propane		58.00	-	58.00	-
Butane		409.00	-	409.00	-
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		5163.00	10627.00	5163.00	10627.00
Nitrogen		-	-	-	-
Design Data:	Number of Tubes:	5	U (BTU/ft^2-F-h)	80	
	Number of Passes:	2			
	Tube Length (ft):	20			
	Tube Diameter (in):	2			
	Exchanger Area (ft^2):	84.3			
	Material of Construction:	Carbon Steel			
Utilities:		COOLING WATER			
Comments:		See Section 6 Process Flow Diagram Section 200			

Pump - 1

Identification:	Item:	*Pump*	Date:	*14 April 2020*
	Item No.:	*P-201*		
	No. Required:	*1*	By:	*[POA]*
Function:	*Pump for transporting boiler feed water to the TLE and increasing the pressure of the stream*			
Operation:	Continuous			
Materials Handled:			**Feed**	**Outlet**
Stream ID:			*BW-1*	*BW-2*
Temperature (F):			212	212
Pressure (psia):			50	470
Mass Flow (lbs/hr):			25528.00	25528.00
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			-	-
Methane			-	-
Ethylene			-	-
Ethane			-	-
Propylene			-	-
Propane			-	-
Butane			-	-
Oxygen			-	-
Carbon Dioxide			-	-
Water			25528.00	25528.00
Nitrogen			-	-
Design Data:	Type	Centrifugal		
	Driver Type	Electric Motor		
	Efficiency	0.81		
	Net Work (HP)	188		
	Head Developed (ft-lbf/lb)	1,010.96		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

Pump - 2

Identification:	Item:	*Pump*	Date:	*14 April 2020*
	Item No.:	*P-202*		
	No. Required:	*1*	By:	*[POA]*
Function:	*Pump for transporting spray cooling water to the quench tower in a recycle loop.*			
Operation:	Continuous			
Materials Handled:			**Feed**	**Outlet**
Stream ID:			*SW-2*	*SW-3*
Temperature (F):			90	90
Pressure (psia):			35	60
Mass Flow (lbs/hr):			185480.00	185480.00
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			-	-
Methane			-	-
Ethylene			-	-
Ethane			-	-
Propylene			-	-
Propane			-	-
Butane			-	-
Oxygen			-	-
Carbon Dioxide			-	-
Water			185480.00	185480.00
Nitrogen			-	-
Design Data:	Type	Centrifugal		
	Driver Type	Electric Motor		
	Efficiency	0.81		
	Drisver Power (HP)	8.3		
	Head Developed (ft-lbf/lb)	46		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

Pump - 3

Identification:	Item:	*Pump*	Date:	*14 April 2020*
	Item No.:	*P-203*		
	No. Required:	*1*	By:	*[POA]*
Function:	*Pump for transporting process steam to the steam cracker.*			
Operation:	Continuous			
Materials Handled:			**Feed**	**Outlet**
Stream ID:			*REC-1*	*PS-1*
Temperature (F):			120	120
Pressure (psia):			14.7	87
Mass Flow (lbs/hr):			2066.00	2066.00
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			-	-
Methane			-	-
Ethylene			-	-
Ethane			-	-
Propylene			-	-
Propane			-	-
Butane			-	-
Oxygen			-	-
Carbon Dioxide			-	-
Water			2066.00	2066.00
Nitrogen			-	-
Design Data:	Type	Centrifugal		
	Driver Type	Electric Motor		
	Efficiency	0.81		
	Net Work (HP)	0.193		
	Head Developed (ft-lbf/lb)	121.33		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

Blower - 1

Identification:	Item:	*Blower*	Date:	*14 April 2020*
	Item No.:	*B-201*		
	No. Required:	*1*	By:	*[POA]*
Function:		*Blower for transporting fuel to the steam cracker firebox.*		
Operation:	Continuous			
Materials Handled:			**Feed**	**Outlet**
Stream ID:			*FU-1*	*FU-2*
Temperature (F):			100	129
Pressure (psia):			58	73
Mass Flow (lbs/hr):			1787.00	1787.00
Component Mass Flow((lbs/hr):				
Polyethylene			-	-
Polypropylene			-	-
Polystyrene			-	-
Char			-	-
Styrene			-	-
Xylene			-	-
Ethylbenzene			-	-
Toluene			-	-
Naphthalene			-	-
Methyl-naphthalene			-	-
Alpha-methyl-styrene			-	-
Hydrogen			606.00	606.00
Methane			599.00	599.00
Ethylene			582.00	582.00
Ethane			-	-
Propylene			-	-
Propane			-	-
Butane			-	-
Oxygen			-	-
Carbon Dioxide			-	-
Water			-	-
Nitrogen			-	-
Design Data:	Type	Centrifugal		
	Driver Type	Electric Motor		
	Isentropic Efficiency	1		
	Net Work (HP)	234		
	Material of Construction:	Aluminium		
Utilities:		ELECTRICITY		
Comments:		See Section 6 Process Flow Diagram Section 200		

iii. Section 300: Separations

Demethanizer					
Identification:	Item:	*Tray Tower*		Date:	*14 April 2020*
	Item No.:	*D-301*			
	No. Required:	*1*		By:	*SME*
Function:		*Separate hydrogen and methane from the heavier hydrocarbons*			
Operation:	Continuous				
Materials Handled:		**Feed**	**Vapor Distillate**	**Liquid Distillate**	**Bototms**
Stream ID:		*SEP-FEED*	*H2-CH4-1*	*C2H4-REC*	*DM-BOT*
Temperature (F):		142.5	-131.2	-131.2	205.1
Pressure (psia):		555	550	550	554.4
Mass Flow (lbs/hr):		5164.04	1702.40	2097.60	1364.04
Component Mass Flow((lbs/l					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		606.59	603.97	2.63	0.00
Methane		606.59	515.34	91.25	0.00
Ethylene		1978.94	538.98	1437.05	2.90
Ethane		218.66	35.37	181.05	2.24
Propylene		1286.89	8.55	373.42	904.92
Propane		52.08	0.16	9.78	42.14
Butane		414.29	0.02	2.42	411.84
Oxygen		-	-	-	-
Carbon Dioxide		-	-	-	-
Water		-	-	-	-
Nitrogen		-	-	-	-
Design Data:	Number of Trays:	15	Inside Diameter:	5.3 ft	
	Number of Passes:	1	Feed Stage:	6	
	Tray type:	Sieve	Mass Reflux Ratio:	5	
	Pressure:	550 psia	Mass Distillate Rate:	3,800 lbs/hr	
	Functional Height:	42.5 ft	Skirt Height:	15 ft	
	Material of Construction:	Carbon Steel	Tray Spacing:	1.5 ft	
Utilities:		LOW PRESSURE STEAM: 3,946.4 LBS/HR			
Comments:		See Section 6 Process Flow Diagram Section 300			

Deethanizer					
Identification:	Item:	*Tray Tower*		Date:	*14 April 2020*
	Item No.:	*D-302*			
	No. Required:	*1*		By:	*SME*
Function:	*Separate the remaining hydrogen and methane from the light and heavy hydrocarbons*				
Operation:	Continuous				
Materials Handled:		**Feed**	**Outlet 1**	**Outlet 2**	**Outlet 3**
Stream ID:		C2H4-REC	H2-CH4-2	C2-OUT	DE-BOT
Temperature (F):		-131.2	-129.8	-44.2	57.5
Pressure (psia):		550	200	203.56	207.2
Mass Flow (lbs/hr):		2097.60	120.00	1500.00	475.18
Component Mass Flow((lbs/l					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		2.63	2.61	0.02	0.00
Methane		91.25	84.02	7.23	0.00
Ethylene		1437.05	33.24	1400.90	2.91
Ethane		181.05	0.13	91.86	89.06
Propylene		373.42	0.00	0.00	373.42
Propane		9.78	0.00	0.00	9.78
Butane		2.42	0.00	0.00	2.42
Oxygen		0.00	0.00	0.00	0.00
Carbon Dioxide		-	-	-	-
Water		-	-	-	-
Nitrogen		-	-	-	-
Design Data:	Number of Trays:	43	Inside Diameter:	8.45 ft	
	Number of Passes:	1	Feed Stage:	29	
	Tray type:	Sieve	Mass Reflux Ratio:	25	
	Pressure:	200 psia	Mass Distillate Rate:	120 lbs/hr	
	Functional Height:	84.5 ft	Skirt Height:	15 ft	
	Material of Construction:	Carbon Steel	Tray Spacing:	1.5 ft	
Utilities:	LOW PRESSURE STEAM: 821.84 LBS/HR				
Comments:	See Section 6 Process Flow Diagram Section 300				

C2-Splitter

Identification:	Item:	*Tray Tower*		Date:	*14 April 2020*
	Item No.:	*D-303*			
	No. Required:	*1*		By:	*SME*
Function:		*Separate ethylene product from ethane to be used as fuel*			
Operation:	Continuous				
Materials Handled:			**Feed**	**Outlet 1**	**Outlet 2**
Stream ID:			C2-FEED	ETHYLENE PRODUT	ETHANE FUEL
Temperature (F):			-41.3	-20.6	17.3
Pressure (psia):			290	290	296.2
Mass Flow (lbs/hr):			1500.00	1410.00	90.00
Component Mass Flow((lbs/l					
Polyethylene			-	-	-
Polypropylene			-	-	-
Polystyrene			-	-	-
Char			-	-	-
Styrene			-	-	-
Xylene			-	-	-
Ethylbenzene			-	-	-
Toluene			-	-	-
Naphthalene			-	-	-
Methyl-naphthalene			-	-	-
Alpha-methyl-styrene			-	-	-
Hydrogen			0.02	0.02	0.00
Methane			7.23	7.23	0.00
Ethylene			1400.90	1395.98	4.92
Ethane			91.86	6.78	85.08
Propylene			0.00	0.00	0.00
Propane			0.00	0.00	0.00
Butane			0.00	0.00	0.00
Oxygen			0.00	0.00	0.00
Carbon Dioxide			-	-	-
Water			-	-	-
Nitrogen			-	-	-
Design Data:	Number of Trays:	23	Inside Diameter:	5.45 ft	
	Number of Passes:	1	Feed Stage:	12	
	Tray type:	Sieve	Mass Reflux Ratio:	10	
	Pressure:	290	Mass Distillate Rate:	1410 lbs/hr	
	Functional Height:	54.5 ft	Skirt Height:	15 ft	
	Material of Construction:	Carbon Steel	Tray Spacing:	1.5 ft	
Utilities:		COOLING WATER: 252.22 LBS/HR			
Comments:		See Section 6 Process Flow Diagram Section 300			

Depropanizer

Identification:	Item:	*Tray Tower*		Date:	*14 April 2020*
	Item No.:	*D-304*			
	No. Required:	*1*		By:	*SME*
Function:		*Separate Propylene product from light hydrocarbons and heavy hydrocarbons*			
Operation:	Continuous				
Materials Handled:		**Feed**	**Outlet 1**	**Outlet 2**	**Outlet 3**
Stream ID:		DP-FEED	C2-FUEL	PROPYLENE PRODUCT	BUTANE FUEL
Temperature (F):		103.2	-11.3	69.2	149.1
Pressure (psia):		207.2	150	154.1	156.9
Mass Flow (lbs/hr):		1841.64	96.00	1250.00	495.65
Component Mass Flow((lbs/hr)					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		0.00	0.00	0.00	0.00
Methane		0.00	0.00	0.00	0.00
Ethylene		5.82	5.33	0.49	0.00
Ethane		91.30	79.68	11.62	0.00
Propylene		1278.34	10.88	1196.54	70.91
Propane		51.92	0.11	40.85	10.96
Butane		414.27	0.00	0.50	413.78
Oxygen		0.00	0.00	0.00	0.00
Carbon Dioxide		-	-	-	-
Water		-	-	-	-
Nitrogen		-	-	-	-
Design Data:	Number of Trays:	40	Inside Diameter:	8.0 ft	
	Number of Passes:	1	Feed Stage:	23	
	Tray type:	Sieve	Mass Reflux Ratio:	42	
	Pressure:	150	Mass Distillate Rate:	96 lbs/hr	
	Functional Height:	80.0 ft	Skirt Height:	15 ft	
	Material of Construction:	Carbon Steel	Tray Spacing:	1.5 ft	
Utilities:		LOW PRESSURE STEAM: 654.64 LBS/HR			
Comments:		See Section 6 Process Flow Diagram Section 300			

C2 Feed Pump

Identification:	Item:	*Feed Pump*		Date:	*14 April 2020*
	Item No.:	*P-301*			
	No. Required:	*1*		By:	*SME*
Function:		*Pressurize C2-OUT stream to send to C2-Splitter Tray Tower*			
Operation:	Continuous				
Materials Handled:				**Feed**	**Outlet**
Stream ID:				C2-OUT	C2-Feed
Temperature (F):				-44.2	-41.3
Pressure (psia):				203.56	300
Mass Flow (lbs/hr):				1500.00	1500.00
Component Mass Flow((lbs/hr)					
Polyethylene				-	-
Polypropylene				-	-
Polystyrene				-	-
Char				-	-
Styrene				-	-
Xylene				-	-
Ethylbenzene				-	-
Toluene				-	-
Naphthalene				-	-
Methyl-naphthalene				-	-
Alpha-methyl-styrene				-	-
Hydrogen				0.02	0.02
Methane				7.23	7.23
Ethylene				1400.90	1400.90
Ethane				91.86	91.86
Propylene				0.00	0.00
Propane				0.00	0.00
Butane				0.00	0.00
Oxygen				0.00	0.00
Carbon Dioxide				-	-
Water				-	-
Nitrogen				-	-
Design Data:	Material of Contruction:	Cast Iron	Type:	Centrifugal	
			Flowrate:	51.52 cuft/hr	
	Net Work:	1.22 hp	Head:	477.0 ft	
	No. Stages:	1	Pump Efficiency:	29.57%	
Utilities:		ELECTRICITY: 0.914 kW			
Comments:		See Section 6 Process Flow Diagram Section 300			

Demethanizer Reflux Pump

Identification:	Item:	*Reflux Pump*		Date:	*14 April 2020*
	Item No.:	*RP-301*			
	No. Required:	*1*		By:	*SME*
Function:	*Pressurize reflux stream from demethanizer condenser to return to demethanizer*				
Operation:	Continuous				
Materials Handled:				**Feed**	**Outlet**
Stream ID:				Demethanizer Reflux	Demethainzer Reflux
Temperature (F):				-131.2	-131.2
Pressure (psia):				562	579
Mass Flow (lbs/hr):				19000.00	19000.00
Component Mass Flow((lbs/hr)					
Polyethylene				-	-
Polypropylene				-	-
Polystyrene				-	-
Char				-	-
Styrene				-	-
Xylene				-	-
Ethylbenzene				-	-
Toluene				-	-
Naphthalene				-	-
Methyl-naphthalene				-	-
Alpha-methyl-styrene				-	-
Hydrogen				3032.97	3032.97
Methane				3032.96	3032.96
Ethylene				9880.20	9880.20
Ethane				1082.13	1082.13
Propylene				1909.86	1909.86
Propane				49.69	49.69
Butane				12.20	12.20
Oxygen				-	-
Carbon Dioxide				-	-
Water				-	-
Nitrogen				-	-
Design Data:	Material of Construction:	Cast Iron	Type:	Centrifugal	
	Net Work:	0.297 hp	Head:	116 ft	
	No. Stages:	1	Pump Efficiency:	70.00%	
Utilities:		ELECTRICITY: 0.2215 kW			
Comments:		See Section 6 Process Flow Diagram Section 300			

Deethanizer Reflux Pump

Identification:	Item:	*Reflux Pump*		Date:	*14 April 2020*
	Item No.:	*RP-302*			
	No. Required:	*1*		By:	*SME*
Function:	*Pressurize reflux stream from deethanizer condenser to return to deethanizer*				
Operation:	Continuous				
Materials Handled:				**Feed**	**Outlet**
Stream ID:				Deethanizer Reflux	Deethainzer Reflux
Temperature (F):				-129.8	-129.8
Pressure (psia):				230	247
Mass Flow (lbs/hr):				3000.00	3000.00
Component Mass Flow((lbs/hr)					
Polyethylene				-	-
Polypropylene				-	-
Polystyrene				-	-
Char				-	-
Styrene				-	-
Xylene				-	-
Ethylbenzene				-	-
Toluene				-	-
Naphthalene				-	-
Methyl-naphthalene				-	-
Alpha-methyl-styrene				-	-
Hydrogen				65.26	65.26
Methane				2100.36	2100.36
Ethylene				831.09	831.09
Ethane				3.30	3.30
Propylene				0.00	0.00
Propane				0.00	0.00
Butane				0.00	0.00
Oxygen				-	-
Carbon Dioxide				-	-
Water				-	-
Nitrogen				-	-
Design Data:	Material of Construction:	Cast Iron	Type:	Centrifugal	
	Net Work:	0.5194 hp	Head:	203 ft	
	No. Stages:	1	Pump Efficiency:	70.00%	
Utilities:		ELECTRICITY: 0.3876 kW			
Comments:		See Section 6 Process Flow Diagram Section 300			

C2-Splitter Reflux Pump

Identification:	Item:	*Reflux Pump*		Date:	*14 April 2020*
	Item No.:	*RP-303*			
	No. Required:	*1*		By:	*SME*
Function:		*Pressurize reflux stream from C2-Splitter condenser to return to C2-Splitter*			
Operation:	Continuous				
Materials Handled:				**Feed**	**Outlet**
Stream ID:				C2-Splitter Reflux	C2-Splitter Reflux
Temperature (F):				-20.6	-20.6
Pressure (psia):				308	325
Mass Flow (lbs/hr):				3000.00	3000.00
Component Mass Flow((lbs/hr)					
Polyethylene				-	-
Polypropylene				-	-
Polystyrene				-	-
Char				-	-
Styrene				-	-
Xylene				-	-
Ethylbenzene				-	-
Toluene				-	-
Naphthalene				-	-
Methyl-naphthalene				-	-
Alpha-methyl-styrene				-	-
Hydrogen				0.16	0.16
Methane				72.26	72.26
Ethylene				13959.78	13959.78
Ethane				67.79	67.79
Propylene				0.00	0.00
Propane				0.00	0.00
Butane				0.00	0.00
Oxygen				-	-
Carbon Dioxide				-	-
Water				-	-
Nitrogen				-	-
Design Data:	Material of Construction:	Cast Iron	Type:	Centrifugal	
	Net Work:	0.3659 hp	Head:	143 ft	
	No. Stages:	1	Pump Efficiency:	70.00%	
Utilities:		ELECTRICITY: 0.2731 kW			
Comments:		See Section 6 Process Flow Diagram Section 300			

Depropanizer Reflux Pump

Identification:	Item:	*Reflux Pump*		Date:	*14 April 2020*
	Item No.:	*RP-304*			
	No. Required:	*1*		By:	*SME*
Function:	*Pressurize reflux stream from depropanizer condenser to return to depropanizer*				
Operation:	Continuous				
Materials Handled:				**Feed**	**Outlet**
Stream ID:				Depropanizer Reflux	Depropainzer Reflux
Temperature (F):				-11.3	-11.3
Pressure (psia):				180	197
Mass Flow (lbs/hr):				4031.80	4031.80
Component Mass Flow((lbs/hr)					
Polyethylene				-	-
Polypropylene				-	-
Polystyrene				-	-
Char				-	-
Styrene				-	-
Xylene				-	-
Ethylbenzene				-	-
Toluene				-	-
Naphthalene				-	-
Methyl-naphthalene				-	-
Alpha-methyl-styrene				-	-
Hydrogen				0.00	0.00
Methane				0.04	0.04
Ethylene				223.78	223.78
Ethane				3346.68	3346.68
Propylene				456.82	456.82
Propane				4.48	4.48
Butane				0.00	0.00
Oxygen				-	-
Carbon Dioxide				-	-
Water				-	-
Nitrogen				-	-
Design Data:	Material of Construction:	Cast Iron	Type:	Centrifugal	
	Net Work:	0.5079 hp	Head:	199 ft	
	No. Stages:	1	Pump Efficiency:	70.00%	
Utilities:		ELECTRICITY: 0.3791 kW			
Comments:		See Section 6 Process Flow Diagram Section 300			

Ethylene Product Storage Tank

Identification:	Item:	*Floating Roof Tank*	Date:	*14 April 2020*
	Item No.:	*T-301*		
	No. Required:	*1*	By:	*SME*
Function:		*Store one hour's worth of Ethylene product*		
Operation:	Continuous			
Materials Handled:				**Feed**
Stream ID:				Ethylene Product
Temperature (F):				70
Pressure (psia):				14.7
Mass Flow (lbs/hr):				1410.00
Component Mass Flow((lbs/hr):				
Polyethylene				-
Polypropylene				-
Polystyrene				-
Char				-
Styrene				-
Xylene				-
Ethylbenzene				-
Toluene				-
Naphthalene				-
Methyl-naphthalene				-
Alpha-methyl-styrene				-
Hydrogen				-
Methane				-
Ethylene				1410.00
Ethane				-
Propylene				-
Propane				-
Butane				-
Oxygen				-
Carbon Dioxide				-
Water				-
Nitrogen				-
Design Data:		Amount stored:	1 hour	
		Inside Diamter:	19.7 ft	
		Functional Height:	59.0 ft	
		Material of Construction:	Carbon Steel	
		Pressure:	14.7	
		Total Storage Volume:	134,193 gallons	
Utilities:				
Comments:		See Section 6 Process Flow Diagram Section 300		

Propylene Product Storage Tank

Identification:	Item:	*Tank*	Date:	*14 April 2020*
	Item No.:	*T-303*		
	No. Required:	*1*	By:	*SME*
Function:		*Store one hours' worth of Popylene product*		
Operation:	Continuous			
Materials Handled:				**Feed**
Stream ID:				Propylene Product
Temperature (F):				70
Pressure (psia):				14.7
Mass Flow (lbs/hr):				1250.00
Component Mass Flow((lbs/hr)				
Polyethylene				-
Polypropylene				-
Polystyrene				-
Char				-
Styrene				-
Xylene				-
Ethylbenzene				-
Toluene				-
Naphthalene				-
Methyl-naphthalene				-
Alpha-methyl-styrene				-
Hydrogen				-
Methane				-
Ethylene				-
Ethane				-
Propylene				1250.00
Propane				-
Butane				-
Oxygen				-
Carbon Dioxide				-
Water				-
Nitrogen				-
Design Data:		Amount stored:	1 hour	
		Inside Diamter:	16.9 ft	
		Functional Height:	50.8 ft	
		Material of Construction:	Carbon Steel	
		Pressure:	14.7	
		Total Storage Volume:	85,704 gallons	
Utilities:				
Comments:		See Section 6 Process Flow Diagram Section 300		

Fuel Storage Tank

Identification:	Item:	*Floating Roof Tank*			Date:	*14 April 2020*
	Item No.:	*T-302*				
	No. Required:	*1*			By:	*SME*
Function:		*Store one hour's worth of hydrogen and hydrocarbons for fuel*				
Operation:	Continuous					
Materials Handled:		**Feed**	**Feed**	**Feed**	**Feed**	**Feed**
Stream ID:		Ethane Fuel	Butane Fuel	HM1	HM2	C2 Fuel
Temperature (F):		17.3	149.1	85	85	70
Pressure (psia):		296.2	156.9	550	200	14.7
Mass Flow (lbs/hr):		90.00	495.65	1702.22	120	96.00
Component Mass Flow((lbs/hr)						
Polyethylene		-	-	-	-	-
Polypropylene		-	-	-	-	-
Polystyrene		-	-	-	-	-
Char		-	-	-	-	-
Styrene		-	-	-	-	-
Xylene		-	-	-	-	-
Ethylbenzene		-	-	-	-	-
Toluene		-	-	-	-	-
Naphthalene		-	-	-	-	-
Methyl-naphthalene		-	-	-	-	-
Alpha-methyl-styrene		-	-	-	-	-
Hydrogen		0.00	0.00	603.97	2.61	0.00
Methane		0.00	0.00	515.35	84.01	0.00
Ethylene		4.92	0.00	538.98	33.24	5.33
Ethane		85.08	0.00	35.37	0.13	79.68
Propylene		0.00	70.91	8.55	0.00	10.88
Propane		0.00	10.96	0.00	0.00	0.11
Butane		0.00	413.78	0.00	0.00	0.00
Oxygen		-	-	0.00	0.00	0.00
Carbon Dioxide		-	-	-	-	-
Water		-	-	-	-	-
Nitrogen		-	-	-	-	-
Design Data:		Amount Stored:		1 hour		
		Inside Diameter:		25.5 ft		
		Functinal Height:		77 ft		
		Material of Construction:		Carbon Steel		
		Pressure:		14.7		
		Total Storage Volume:		290,550 gallons		
Utilities:						
Comments:		See Section 6 Process Flow Diagram Section 300				

iv. Section 400: Refrigeration System

Refrigeration Compressor					
Identification:	Item:	*Compressor*		Date:	*14 April 2020*
	Item No.:	*C-401*			
	No. Required:	*1*		By:	*SME*
Function:			*Describe the function of the unit*		
Operation:	Continuous				
Materials Handled:				**Feed**	**Outlet**
Stream ID:				REF-FEED	COMP-REF
Temperature (F):				85	100
Pressure (psia):				30	2000
Mass Flow (lbs/hr):				66000	66000
Component Mass Flow((lbs/hr):					
Polyethylene				-	-
Polypropylene				-	-
Polystyrene				-	-
Char				-	-
Styrene				-	-
Xylene				-	-
Ethylbenzene				-	-
Toluene				-	-
Naphthalene				-	-
Methyl-naphthalene				-	-
Alpha-methyl-styrene				-	-
Hydrogen				-	-
Methane				-	-
Ethylene				66000	66000
Ethane				-	-
Propylene				-	-
Propane				-	-
Butane				-	-
Oxygen				-	-
Carbon Dioxide				-	-
Water				-	-
Nitrogen				-	-
Design Data:		Material of Construction:	Carbon Steel		
		Net Work:	5810 hp		
		No. Stages:	1		
		Type:	Compressor		
		Flowrate:	452,497 cuft/hr		
Utilities:		ELECTRICITY:	4332.516 kW		
Comments:			See Section 6 Process Flow Diagram Section 400		

Plate-Fin Exchanger

Identification:	Item:	*Heat Exchanger*				Date:	*14 April 2020*	
	Item No.:	*H-401*						
	No. Required:	*1*				By:	*SME*	
Function:		*Exchange heat among refrigeration streams*						
Operation:	Continuous							
Materials Handled:		**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
Stream ID:		*COMP-REF*	*H2-CH4-1*	*H2-CH4-2*	*R1*	*R2*	*F-1-V*	*F-2-V*
Temperature (F):		100	-131.2	-129.8	-143.69	-29.56	-29.06	-143.69
Pressure (psia):		2000	550	200	21	250	252	21
Mass Flow (lbs/hr):		66000.00	1702.22	120.00	24925.63	19000.00	8397.41	13676.95
Component Mass Flow((lbs								
Hydrogen		0.00	603.97	2.61	0.00	0.00	0.00	0.00
Methane		0.00	515.35	84.01	0.00	0.00	0.00	0.00
Ethylene		66000.00	538.98	33.24	24925.63	19000.00	8397.41	13676.95
Ethane		0.00	35.37	0.13	0.00	0.00	0.00	0.00
Propylene		0.00	8.55	0.00	0.00	0.00	0.00	0.00
Propane		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butane		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide		-	-	-	-	-	-	-
Water		-	-	-	-	-	-	-
Nitrogen		-	-	-	-	-	-	-
		O1	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**
		COLD-REF	*HM1*	*HM2*	*R1-W*	*F2V-W*	*R2-W*	*F1V-W*
		4.6	85	85	85	85	85	85
		2000	550	200	21	21	250	252
		66000.00	1702.22	120.00	24925.63	13676.95	19000.00	8397.41
Hydrogen		0.00	603.97	2.61	0.00	0.00	0.00	0.00
Methane		0.00	515.35	84.01	0.00	0.00	0.00	0.00
Ethylene		66000.00	538.98	33.24	24925.63	13676.95	19000.00	8397.41
Ethane		0.00	35.37	0.13	0.00	0.00	0.00	0.00
Propylene		0.00	8.55	0.00	0.00	0.00	0.00	0.00
Propane		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butane		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide		-	-	-	-	-	-	-
Water		-	-	-	-	-	-	-
Nitrogen		-	-	-	-	-	-	-
Design Data:		Material of Construction:			Stainless Steel			
		Type:			Plate-Fin Heat Exchanger			
		Duty:			-4774835.37 BTU/hr			
		Heat Transfer Coefficient:			60 BTU/(F ft^2 hr)			
		Heat Transfer Area:			6788.96 sqft			
Utilities:								
Comments:		See Section 6 Process Flow Diagram Section 400						

Flash Vessel 1

Identification:	Item:	*Flash Drum*		Date:	*14 April 2020*
	Item No.:	*F-401*			
	No. Required:	*1*		By:	*SME*
Function:	*Flash separate the ethylene refrigerant to be used in the separation train*				
Operation:	Continuous				
Materials Handled:		**Feed**	**Vapor Outlet**	**Liquid Outlet 1**	**Liquid Outlet 2**
Stream ID:		COLD-REF	F-1-V	C2-DEPROP-FEED	T-F-2
Temperature (F):		4.6	-29.06	-29.06	-29.06
Pressure (psia):		2000	252	252	252
Mass Flow (lbs/hr):		66000.00	8397.41	19000.00	38602.59
Component Mass Flow((lbs/hr):					
Polyethylene		-	-	-	-
Polypropylene		-	-	-	-
Polystyrene		-	-	-	-
Char		-	-	-	-
Styrene		-	-	-	-
Xylene		-	-	-	-
Ethylbenzene		-	-	-	-
Toluene		-	-	-	-
Naphthalene		-	-	-	-
Methyl-naphthalene		-	-	-	-
Alpha-methyl-styrene		-	-	-	-
Hydrogen		0.00	0.00	0.00	0.00
Methane		0.00	0.00	0.00	0.00
Ethylene		66000.00	8397.41	19000.00	38602.59
Ethane		0.00	0.00	0.00	0.00
Propylene		0.00	0.00	0.00	0.00
Propane		0.00	0.00	0.00	0.00
Butane		0.00	0.00	0.00	0.00
Oxygen		0.00	0.00	0.00	0.00
Carbon Dioxide		-	-	-	-
Water		-	-	-	-
Nitrogen		-	-	-	-
Design Data:		Vapor Fraction:	0.127		
		Pressure Drop:	1748 psia		
		Functional Height:	13.5 ft		
		Diameter:	4.5 ft		
		Volume:	1,640 gallons		
Utilities:					
Comments:	See Section 6 Process Flow Diagram Section 400				

Flash Vessel 2					
Identification:	Item:	*Flash Drum*		Date:	*14 April 2020*
	Item No.:	*F-402*			
	No. Required:	*1*		By:	*SME*
Function:		*Flash separate the ethylene refrigerant to be used in the separation train*			
Operation:	Continuous				
Materials Handled:			**Feed**	**Vapor Outlet**	**Liquid Outlet 1**
Stream ID:			T-F-2	F-2-V	DM-DE
Temperature (F):			-29.06	-143.69	-143.69
Pressure (psia):			252	21	21
Mass Flow (lbs/hr):			38602.59	13676.95	24925.63
Component Mass Flow((lbs/hr):					
Polyethylene			-	-	-
Polypropylene			-	-	-
Polystyrene			-	-	-
Char			-	-	-
Styrene			-	-	-
Xylene			-	-	-
Ethylbenzene			-	-	-
Toluene			-	-	-
Naphthalene			-	-	-
Methyl-naphthalene			-	-	-
Alpha-methyl-styrene			-	-	-
Hydrogen			0.00	0.00	0.00
Methane			0.00	0.00	0.00
Ethylene			38602.59	13676.95	24925.63
Ethane			0.00	0.00	0.00
Propylene			0.00	0.00	0.00
Propane			0.00	0.00	0.00
Butane			0.00	0.00	0.00
Oxygen			0.00	0.00	0.00
Carbon Dioxide			-	-	-
Water			-	-	-
Nitrogen			-	-	-
Design Data:		Vapor Fraction:	0.354		
		Pressure Drop:	231 psia		
		Functional Height:	11.0 ft		
		Diameter:	3.65 ft		
		Volume:	860 gallons		
Utilities:					
Comments:		See Section 6 Process Flow Diagram Section 400			

Section 12. Equipment Cost Summary

The following table highlights the purchase costs and bare module costs of all equipment in this process. Design specifications of equipment were determined from ASPEN simulations and hand calculations. Equipment costs were calculated using equations presented in Chapter 16 of *Seider et al.* The total cost of equipment is $21.35MM.

Table 12.1: Summary table for process equipment and machinery

EQUIPMENT DESCRIPTION	TYPE	PURCHASE COST	BARE MODULE FACTOR	BARE MODULE COST
RP-301	Process Machinery	$4,555	3.30	$15,032
RP-302	Process Machinery	$5,370	3.30	$17,721
RP-303	Process Machinery	$4,546	3.30	$15,002
RP-304	Process Machinery	$5,038	3.30	$16,625
P-302	Process Machinery	$5,667	3.30	$18,701
P-201	Process Machinery	$4,770	3.30	$15,741
P-202	Process Machinery	$4,581	3.30	$15,117
P-203	Process Machinery	$11,393	3.30	$37,597
B-101	Process Machinery	$8,820	2.15	$18,963
B-102	Process Machinery	$8,820	2.15	$18,963
B-201	Process Machinery	$14,604	2.15	$31,399
C-401	Process Machinery	$2,226,011	2.15	$4,785,924
C-201	Process Machinery	$392,000	2.15	$842,800
C-202	Process Machinery	$61,447	2.15	$132,111
C-203	Process Machinery	$35,079	2.15	$75,420
C-204	Process Machinery	$34,706	2.15	$74,618
H-401	Fabricated Equipment	$512,053	3.17	$1,623,208
C-301	Fabricated Equipment	$22,835	3.17	$72,387
C-302	Fabricated Equipment	$13,243	3.17	$41,980
C-303	Fabricated Equipment	$172,944	3.17	$548,232
C-304	Fabricated Equipment	$15,630	3.17	$49,547
E-301	Fabricated Equipment	$14,990	3.17	$47,518
E-302	Fabricated Equipment	$17,589	3.17	$55,757
E-303	Fabricated Equipment	$13,175	3.17	$41,765
E-304	Fabricated Equipment	$16,489	3.17	$52,270
HX-202	Fabricated Equipment	$16,302	3.17	$51,677
HX-203	Fabricated Equipment	$12,001	3.17	$38,043

HX-204	Fabricated Equipment	$12,370	3.17	$39,213
HX-205	Fabricated Equipment	$12,459	3.17	$39,495
HX-206	Fabricated Equipment	$12,613	3.17	$39,983
HX-201	Fabricated Equipment	$16,302	3.17	$51,677
F-401	Fabricated Equipment	$136,099	4.16	$566,172
F-402	Fabricated Equipment	$36,129	4.16	$150,297
R-301	Fabricated Equipment	$152,261	4.16	$633,406
R-302	Fabricated Equipment	$14,068	4.16	$58,523
R-303	Fabricated Equipment	$82,433	4.16	$342,921
R-304	Fabricated Equipment	$18,686	4.16	$77,734
R-101	Fabricated Equipment	$167,171	4.16	$695,431
QT-201	Fabricated Equipment	$20,329	4.16	$84,569
E-102	Fabricated Equipment	$11,246	4.16	$46,783
D-301	Fabricated Equipment	$227,850	4.16	$947,856
D-302	Fabricated Equipment	$385,971	4.16	$1,605,639
D-303	Fabricated Equipment	$183,872	4.16	$764,908
D-304	Fabricated Equipment	$307,482	4.16	$1,279,125
T-301	Storage	$199,996	4.00	$799,984
T-303	Storage	$159,328	4.00	$637,312
T-302	Storage	$295,879	4.00	$1,183,516
T-101	Storage	$83,332	4.00	$333,328
T-102	Storage		4.00	
T-001	Storage	$45,707	3.21	$146,719
T-002	Storage	$45,707	3.21	$146,719
E-002	Fabricated Equipment	$2,883	3.21	$9,254
E-001	Fabricated Equipment	$23,534	3.21	$75,544
E-003	Fabricated Equipment	$11,642	3.21	$37,371
E-101	Fabricated Equipment	$500,000	3.21	$1,605,000
HX-SPARE	Spares	$16,302	3.17	$51,677
P-SPARE1	Spares	$4,770	3.30	$15,741
P-SPARE2	Spares	$4,581	3.30	$15,117
P-SPARE3	Spares	$11,393	3.30	$37,597
B-SPARE	Spares	$14,604	2.15	$31,399
TOTAL				***$21,349,818***

A breakdown of costs is shown in the figure below:

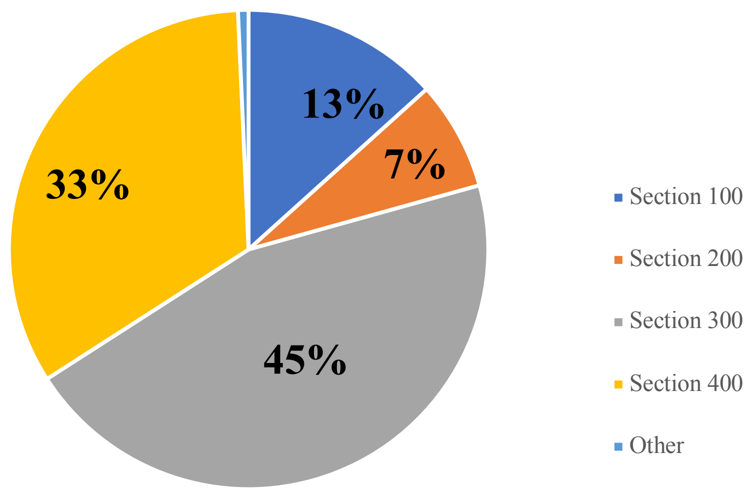

Figure 12.1: A breakdown of equipment capital costs of the plant

58 units were accounted for in Table 20.1, nine from Section 000-100, 15 from Section 200, 25 from Section 300, four from Section 400, and five units in other. Section 400, the refrigeration cycle, has the least number of units but accounts for 33% of total equipment costs. The compressor (C-401) in the refrigeration cycle is the most expensive unit in the plant and its bare module cost is $4.79MM. The compressor is that expensive because it compresses 66,000 lb/hr of ethylene gas from 30 psia to 2000 psia. Even though temperature only increases from 85°F to 100°F, ethylene will still be a gas. Section 300, separation processes, accounts for almost half of the total equipment costs. The most expensive units in Section 300 are distillation columns and the storage tanks. All the columns are made of carbon steel, the cheapest material, and they can withstand pressures of up to 15,000 psia. We considered having more storage tanks in a previous design, but we opted to store all recovered fuel in a storage tank.

Section 13. Fixed Capital Investment Summary

The total capital investment for the project was determined to be \$27.5 MM. This value was calculated using the method from Chapter 16 of Seider et al. The calculation sequence can be seen in the table below.

Table 13.1: Relationship bare-module investment, direct permanent investment, depreciable capital, permanent investment, and capital investment

Total bare-module costs for fabricated equipment	C_{FE}					
Total bare-module costs for process machinery	C_{PM}					
Total bare-module costs for spares	C_{spare}					
Total bare-module costs for storage and surge tanks	$C_{storage}$					
Total cost for initial catalyst charges	$C_{catalyst}$					
Total bare-module costs for computers and software etc.	C_{comp}					
Total bare-module investment, TBM		C_{TBM}				
Cost of site preparation		C_{site}				
Cost of service facilities		C_{serv}				
Allocated costs for utility plants and related facilities		C_{alloc}				
Total of direct permanent investment, DPI			C_{DPI}			
Cost of contingencies and contractor's fee			C_{cont}			
Total depreciable capital, TDC				C_{TDC}		
Cost of land				C_{land}		
Cost of royalties				C_{royal}		
Cost of plant startup				$C_{startup}$		
Total permanent investment, TPI					C_{TPI}	
Working capital					C_{WC}	
Total capital investment, TCI						C_{TCI}

The costs of certain factors such as site preparations and service facilities were not as clear as others. The table below shows the assumptions that were made in calculating the total capital investment.

Table 13.2: Assumptions made to calculate require fees in the total capital investment.

Cost of site preparations	5% of Total bare-module costs
Cost of service facilities	5% of Total bare-module costs
Cost of contingencies and contractor fees	18% of Direct permanent investment
Cost of land	2% of Total depreciable capital
Cost of plant start-up	10% of Total depreciable capital

Table 13.3: Further analysis on total capital investment and working capital.

Investment Summary			
Total Bare Module Costs:			
-	Fabricated Equipment	$ 11,773,287	
	Process Machinery	$ 6,177,421	
	Spares	$ 151,531	
	Storage	$ 3,247,579	
	Other Equipment	$ -	
	Catalysts	$ -	
	Computers, Software, Etc.	$ -	
	Total Bare Module Costs:		**$ 21,349,818**
Direct Permanent Investment			
	Cost of Site Preparations:	$ 1,067,491	
	Cost of Service Facilities:	$ 1,067,491	
	Allocated Costs for utility plants and facilities:	$ -	
	Direct Permanent Investment		**$ 23,484,799**
Total Depreciable Capital			
	Cost of Contingencies & Contractor Fees	$ 4,227,264	
	Total Depreciable Capital		**$ 27,712,063**
Total Permanent Investment			
	Cost of Land:	$ 554,241	

Cost of Royalties:	$ -	
Cost of Plant Start-Up:	$ 2,771,206	
Total Permanent Investment - Unadjusted		$ 31,037,511
Site Factor		0.85
Total Permanent Investment		**$ 26,381,884**

Working Capital

	2023	2024	2025
Accounts Receivable	$ 570,231	$ 285,116	$ 285,116
Cash Reserves	$ 437,430	$ 218,715	$ 218,715
Accounts Payable	$ (377,519)	$ (188,759)	$ (188,759)
Ethylene & Propylene Inventory	$ 76,031	$ 38,015	$ 38,015
Raw Materials	$ 15,800	$ 7,900	$ 7,900
Total	**$ 721,973**	**$ 360,986**	**$ 360,986**
Present Value at 15%	*$ 627,802*	*$ 272,958*	*$ 237,354*
Total Capital Investment			**$ 27,519,998**

Section 14. Operating Cost-Cost of Manufacture

i. Variable Costs

Annual variable operating costs were calculated to be $5MM and this includes the costs of raw material, general expenses, utilities, and revenue generated from byproducts. The following table summarizes the variable costs for this process.

Table 15.1: Summary of Variable Costs

Variable Costs at 100% Capacity:			
General Expenses			
	Selling / Transfer Expenses:		$ 462,521
	Direct Research:		$ 740,033
	Allocated Research:		$ 77,087
	Administrative Expense:		$ 308,347
	Management Incentive Compensation:		$ 192,717
Total General Expenses			$ 1,780,705
Raw Materials	$0.288846	per lb of Ethylene & Propylene	$6,453,981
- ***Byproducts***	$0.314617	per lb of Ethylene & Propylene	($7,029,792)
- ***Utilities***	$0.170033	per lb of Ethylene & Propylene	$3,799,211
Total Variable Costs			**$ 5,004,105**

The raw materials in this process are LDPE, HDPE, PP, and PS plastic shards. The total feed rate is 70 MT/day or 6,430 lb/hr. Unlike the other monomers that are produced in the rotary kiln, styrene does not proceed through the process as it is the primary component of the pyrolytic oil. Ethylene was also purchased as a raw material for the start-up of the refrigeration cycle.

The byproducts from the process are 450 psig steam, chilled water, and pyrolytic oil. High pressure steam is generated when boiler water undergoes a phase change while quenching cracked gases in the transfer line exchanger. Chilled water is generated in the reboiler of the C2 splitter column (D-303) as cooling water is used to heat the boil-up stream Some of the chilled water is sent to HX-202, while the rest is sold as a byproduct. Pyrolytic oil that was not burned in the rotary kiln was sold as a byproduct as well.

Utilities used in the process are boiler feed water, cooling water, low pressure steam, refrigerant, and electricity. Boiler feed water was used for quenching the cracked gases in the transfer line exchanger, cooling water was used as a coolant in heat exchangers and in the quench tower, refrigerant was bought for start-up purposes in the plate-fin exchanger in the refrigeration cycle, and low pressure steam was used to heat reboilers in the demethanizer (D-301), deethanizer (D-302), and depropanizer (D-304) columns. Electricity is the most expensive utility in the process and it is used in pumps, compressors, and to power units in Section 100.

Table 15.2: Summary of Raw Materials, Byproducts, and Utilities in the process

	Item	**Ratio Required (per lb of Ethylene and Propylene)**	**Unit Cost**	**Annual Demand**	**Annual Cost/Sale**
Raw Material	Plastic shards	0.0011 MT	$261.54	24,500 MT	$6.41MM
	Ethylene	0.00295 lb	$0.70	66,000 lb	$46,200
Byproducts	450 psig steam	1.56 lb	$.008	34.97MM lb	$279.788
	Chilled Water	.00752 ton-day	$1.50	168,021 ton-day	$252,031
	Pyrolytic Oil	0.254 lb	$0.70	5.67MM lb	$3.97MM
Utilities	Cooling water	57.85 gal	$0.0001	155.96MM gal	$15,496
	50 psig steam	2.046 lb	$.06	45.71MM lb	$274,250
	-30F, Refrigerant	0.0001 ton-day	$4.00	2,165 ton-day	$8,660
	Electricity	2.232 kWh	$0.07	49.89MM kWh	$3.80 MM
	Boiler Feed Water	0.188 gal	$.02	4.19MM gal	$8,385

ii. Fixed Costs

Fixed costs were calculated to be \$8.03MM per year. This includes the costs for operations, maintenance, and operating overhead as well as property taxes and insurance. We assumed that we would need four working shifts with five operators per shift. There will be four teams, one working a 12-hr day shift and another working a 12-hr night shift, while two teams are off over a four day period. The rotating work schedule will be 4 days on and 4 days off. At the plant there will be two consoles, each with one operator, and there will be three process technicians in the field. The technical assistance to manufacturing costs account for two process engineers and two process control engineers that work regular 40-hr weeks. This work schedule was recommended by an industrial consultant. The following table presents a summary of our fixed costs.

Table 15.3: Summary of fixed costs estimated for the project on an annual basis.

Operations		
	Direct Wages and Benefits	$ 1,664,000
	Direct Salaries and Benefits	$ 249,600
	Operating Supplies and Services	$ 99,840
	Technical Assistance to Manufacturing	$ 1,800,000
	Control Laboratory	$ -
	Total Operations	**$ 3,813,440**
Maintenance		
	Wages and Benefits	$ 1,247,043
	Salaries and Benefits	$ 311,761
	Materials and Services	$ 1,247,043
	Maintenance Overhead	$ 62,352
	Total Maintenance	**$ 2,868,199**
Operating Overhead		
	General Plant Overhead:	$ 246,541
	Mechanical Department Services:	$ 83,338
	Employee Relations Department:	$ 204,872
	Business Services:	$ 256,958
	Total Operating Overhead	**$ 791,708**
Property Taxes and Insurance		
-	Property Taxes and Insurance:	$ 554,241
Other Annual Expenses		
	Rental Fees (Office and Laboratory Space):	$ -
	Licensing Fees:	$ -
	Miscellaneous:	$ -
	Total Other Annual Expenses	**$ -**
Total Fixed Costs		**$ 8,027,588**

Section 15. Other Important Considerations

i. Environmental Factors

The main motivation of this project is to reduce the amount of plastic waste that gets disposed of in harmful ways, such as being dumped into the ocean or being incinerated dangerously close to habitation. One obvious way in which our project meets this goal is that it takes plastic waste in as its feed and prevents that plastic waste from reaching the ocean or incineration facilities. Given a feed of 68.9 tons of plastic each day, this corresponds to an annual 25,150 tons of plastic waste that are saved from dangerous disposal. This is only 0.3% of the 8 *million* tons of plastic waste that get dumped into the ocean each year— one plant will not be enough to eliminate the world's plastic waste problem. However, if similar plants were built around the world, it is conceivable that a significant portion of the world's plastic waste could be dealt with in a more sustainable manner.

Another important metric of success for our project is how well it can reduce the need for additional plastic to be created. Of the 68.9 tons of plastic waste entering the system each day, 40.14% is converted into ethylene and propylene by mass. These monomers can be used to create plastic resin through polymerization—ethylene can be polymerized to polyethylene, and propylene can be polymerized to polypropylene. These resins can then be used to make plastic products. How much of our plastic waste feed gets converted into these products relies in part on the efficiency of these processes, in addition to our own. Given that an estimated 300MM tons of plastic are produced each year, our annual ethylene and propylene output of 7,980 tons seems woefully small, but, again, if several such plants were built around the world, it is possible that we could significantly reduce the need to create new plastic material.

The process itself could also be modified to increase the ethylene and propylene yield—but as of now, that is an expensive proposition. The catalysts that we considered for our process each had their own problems, but some of them had higher yields of light hydrocarbons, meaning that a greater amount of pyrolytic product could be cracked in the steam cracker to produce the desired products.

Plastic waste is not the only problem that currently threatens the environment. Greenhouse gas emission is a huge contributor to global climate change, which poses a huge threat to humanity and all organisms. Industrial processes are one of the most significant sources of greenhouse gas emission. It is important for our project not to offset the good done for the environment by emitting a large amount of CO_2 into the atmosphere. A chemical plant is considered to be a very significant greenhouse gas emitter if it produces a high-digit six-figure number of tons of greenhouse gas annually, a significant greenhouse gas emitter if it produces a low-digit six-figure number of tons of greenhouse gas annually, and a moderate greenhouse gas emitter if it produces 100,000 tons or less of greenhouse gas annually. Our process produces 3,706 tons of CO_2 annually, meaning that we produce far less than even a moderate greenhouse gas emitter. So, our goal to create an environmentally beneficial process without offsetting these benefits with greenhouse gas emissions was successful.

ii. Safety Factors

The rotary kiln operates at high temperatures and poses a risk to plant operators if they get too close. To prevent any dangerous accidents, it is important to monitor the temperature of the kiln to ensure that it does not reach extreme temperatures. Devices such as UV detectors can be used to monitor the kiln temperature.

The storage tanks all contain flammable hydrocarbon gas. To prevent explosions, the pressure of the storage tanks is maintained at 30 psia, so that in the case of a puncture, gas would flow out to the atmosphere rather than air flowing in. It is dangerous for oxygen to enter the tanks because it makes ignition and explosions possible.

iii. Global factors

Plastic waste is a threat across the globe. As discussed in the introduction, big plastic buyers like China have stopped purchasing plastic waste, and now other countries, mainly in Southeast Asia, have stepped in to become the primary purchasers. However, much of this plastic waste is disposed of in ways that are harmful to the environment and the people who live near the disposal plants. Incineration plants emit harmful compounds into the atmosphere that nearby habitants may breathe in, resulting in health problems. The fumes are also unpleasant and affect the quality of life for habitants living near the plant. Implementing recycling processes like the one proposed in this project could benefit communities throughout the world that suffer as a result of dangerous plastic waste disposal. For this reason, countries that are being overwhelmed with plastic waste stand to benefit the most from chemical recycling facilities.

This was one reason that Indonesia was selected for the plant location. Indonesia is believed to be the second-largest contributor to plastic waste ocean pollution, behind China [1]. While Indonesia is not a major plastic purchaser like many of its neighbors in Southeast Asia, its waterways are among the most polluted in the world, because the Indonesian population generates tons of plastic waste annually. Building a chemical recycling plant here would allow for convenient sourcing of plastic waste; because there is already so much plastic waste in Indonesia, transportation of plastic waste from faraway countries would not be necessary.

iv. Robustness of feedstock

It is interesting to consider the feedstock as proposed by the project author. The feed to the process is PE, PP, and PS, which are selected as they are entirely composed of carbon and hydrogen. Introducing other types of plastic, notably PVC and PET, presents hazards due to oxygen and chlorine content, and thus other methods of recycling need be considered for those plastics. Due to the stability of the aromatic rings of polystyrene, polystyrene is converted to other aromatic compounds, namely styrene, toluene, and ethylbenzene. In this sense, polystyrene is primarily useful in the production of fuel oils from plastic waste, or in the production of styrene itself. Additionally, polystyrene has a significantly higher melting point than polypropylene and polyethylene, which increases electricity demands on the plastic extruder. It follows that in a pilot scale plant, excluding polystyrene from a feedstock should be considered, as its utility for making ethylene and propylene is minimal.

Section 16. Profitability Analysis

i. Profitability Metrics

The proposed process for chemical recycling of mixed plastic waste is not a profitable venture. The Net Present Value of the recycling plant in 2022 is -$18.8MM, and the Internal Rate of Return (IRR) is -4.72%. In the third year of production, a -2.12% Return on Investment (ROI) is obtained. The table below summarizes key profitability insights at a nominal interest rate of 15%:

Table 16.1: Profitability Measures for the proposed process of chemical recycling.

Profitability Measures

The Internal Rate of Return (IRR) for this project is	-4.47%
The Net Present Value (NPV) of this project in 2022 is	$ (18,605,100)

ROI Analysis (Third Production Year)

Annual Sales	**13,875,624**
Annual Costs	**(12,489,703)**
Depreciation	**(2,110,551)**
Income Tax	**166,665**
Net Earnings	**(557,965)**
Total Capital Investment	**27,825,830**
ROI	**-2.01%**

This financial assessment is based on the following timeline: the plant is designed in one year (2022), constructed in the next year (2023), and operated for the following fifteen years (2024-2038). The following table summarizes this trajectory:

Table 16.2: Chronology of the proposed plant. One year will be used for design, one year for construction, and fifteen for production of ethylene and propylene product.

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2022	Design		0.0%		
2023	Construction	100%	0.0%		
2024	Production	0%	45.0%	20.00%	$0.69
2025	Production	0%	67.5%	32.00%	$0.69
2026	Production	0%	90.0%	19.20%	$0.69
2027	Production		90.0%	11.52%	$0.69
2028	Production		90.0%	11.52%	$0.69
2029	Production		90.0%	5.76%	$0.69
2030	Production		90.0%		$0.69
2031	Production		90.0%		$0.69
2032	Production		90.0%		$0.69
2033	Production		90.0%		$0.69
2034	Production		90.0%		$0.69
2035	Production		90.0%		$0.69
2036	Production		90.0%		$0.69
2037	Production		90.0%		$0.69
2038	Production		90.0%		$0.69

This process has a negative IRR and a negative NPV, meaning that it does not produce value. A large contributor to these negative values is the large annual cost associated with running this plant. At 90% capacity, variable costs for the process are $4.5MM, and fixed costs are $8MM, equaling $12.5MM in total annual cost. Annual sales are $13.9MM, just $1.4MM more than annual cost. With depreciation and taxes, this leads to net earnings of -$560,000 in the third year of production. The plant earns negative dollars until 2030, when it finally begins to generate positive net earnings.

If this plant were built, it would require one year for design (2022) and one year for construction (2023), followed by a lifespan of fifteen years (2024-2038) of ethylene and propylene production. During the first year of production, 45% of plant capacity is reached. During the second year of operation, 68% of plant capacity is reached. For the remaining thirteen years of operation, 90% of plant capacity is reached, where 100% capacity is 70 MT per day feed of plastic waste. The following table summarizes the cashflow of the plant for the entire fifteen-year lifespan:

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2022	0%		-	-	-	-	-	-	-	-	-	-	-	-
2023	0%		-	(26,381,900)	(720,400)	-	-	-	-	-	-	-	(27,102,300)	(23,567,200)
2024	45%	$0.69	6,937,800	-	(360,200)	(2,251,800)	(8,027,600)	(5,542,400)	-	(8,884,000)	2,043,300	(6,840,700)	(1,658,500)	(24,821,200)
2025	68%	$0.69	10,406,700	-	(360,200)	(3,377,800)	(8,027,600)	(8,867,900)	-	(9,866,500)	2,269,300	(7,597,200)	910,500	(24,222,600)
2026	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	(5,320,700)	-	(3,976,400)	914,600	(3,061,800)	2,258,900	(22,931,100)
2027	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	(3,192,400)	-	(1,848,100)	425,100	(1,423,000)	1,769,400	(22,051,300)
2028	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	(3,192,400)	-	(1,848,100)	425,100	(1,423,000)	1,769,400	(21,286,400)
2029	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	(1,596,200)	-	(251,900)	57,900	(193,900)	1,402,300	(20,759,200)
2030	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(20,420,800)
2031	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(20,126,600)
2032	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(19,870,700)
2033	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(19,648,200)
2034	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(19,454,700)
2035	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(19,286,500)
2036	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(19,140,200)
2037	90%	$0.69	13,875,600	-	-	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	1,035,100	(19,013,000)
2038	90%	$0.69	13,875,600	-	1,440,800	(4,503,700)	(8,027,600)	-	-	1,344,300	(309,200)	1,035,100	2,475,900	(18,748,400)

Table 16.2: Cashflow Spreadsheet for fifteen years of operation of chemical plant

The following figure summarizes the cumulative NPV at 15% for the two years prior to operation and the fifteen-year operation period:

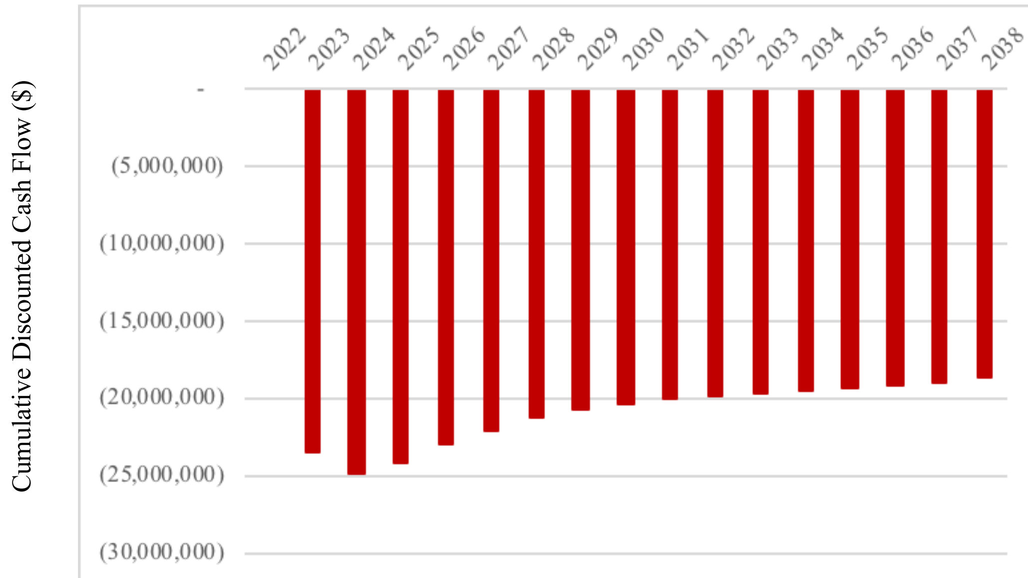

Figure 16.1: Cumulative discounted cash flow for the proposed chemical recycling process. The plant has an NPV of -$18.8MM. The process does not break even after 15 years of operation.

The following figure summarizes net earnings for the two years prior to operation and for the fifteen-year operation period:

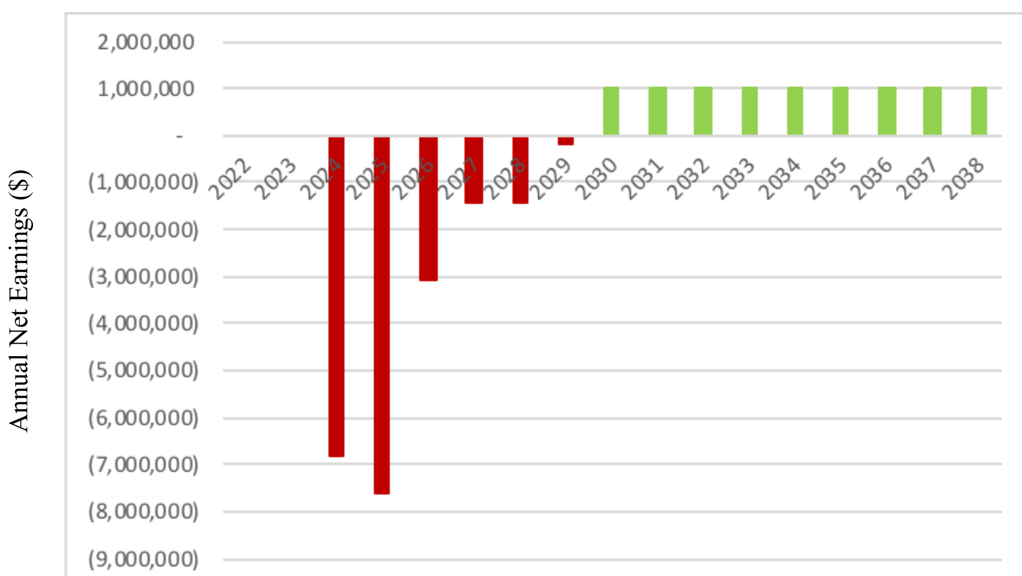

Figure 16.2: Annual net earnings ($) for the proposed process of chemical recycling. The plant has an NPV of -$18.8MM. The process does not break even after 15 years of operation.

In 2030, the plant begins to generate positive annual earnings. To breakeven, the plant would need to operate for an additional seventeen years, after which point it could begin turning a profit. This means that a total of thirty-two years of operation are required to even reach the breakeven point, which is an unrealistic amount of time to wait to breakeven.

ii. Sensitivity Analyses

The profitability analysis was performed using a product price of $0.69 and an annual variable cost of $4.5MM. It would be beneficial to examine how product price point and annual variable costs affect the profitability of the plant. Given our current annual variable costs, a product price of $0.76 per pound would result in a positive IRR. It would be worth investigating the possibility of pricing our product slightly above market value. Typically, ethylene and propylene sell for roughly $0.70 per pound. However, some companies might be willing to pay a slightly higher price for our product since it is generated using a green process; it is possible that companies that source their plastic feedstock from a green facility rather than the typical petrol plant could receive tax credit or a government subsidy for being more sustainable. Depending on the size of the credit, this could serve as incentive to choose our product over other, cheaper feedstock options.

The table on the following page shows a sensitivity analysis for the Internal Rate of Return in several different scenarios of product price and variable costs, with the current IRR scenario highlighted in red, and acceptable-IRR scenarios (those above an IRR of 12%) highlighted in green:

Sensitivity Analyses

Product Price		Variable Costs: $2,502,053	$3,002,463	$3,502,874	$4,003,284	$4,503,695	***$5,004,105***	$5,504,516	$6,004,927	$6,505,337	$7,005,748	$7,506,158
		0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
$0.35	0.5	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.41	0.6	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.48	0.7	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.55	0.8	-8.45%	-12.63%	-19.11%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.62	0.9	-0.17%	-2.41%	-4.99%	-8.07%	-12.05%	-17.95%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$0.69	1	5.46%	3.78%	1.97%	0.00%	-2.20%	-4.72%	-7.71%	-11.50%	-16.94%	Negative IRR	Negative IRR
$0.76	1.1	10.02%	8.61%	7.13%	5.56%	3.90%	2.11%	0.16%	-2.00%	-4.46%	-7.37%	-11.00%
$0.83	1.2	13.98%	12.72%	11.43%	10.08%	8.68%	7.21%	5.66%	4.02%	2.25%	0.32%	-1.80%
$0.90	1.3	17.56%	16.41%	15.23%	14.02%	12.77%	11.49%	10.15%	8.76%	7.30%	5.76%	4.13%
$0.97	1.4	20.87%	19.80%	18.70%	17.58%	16.44%	15.27%	14.06%	12.82%	11.54%	10.21%	8.83%
$1.04	1.5	23.99%	22.97%	21.94%	20.88%	19.81%	18.72%	17.61%	16.47%	15.30%	14.10%	12.87%

Table 16.3: Sensitivity analysis for different product price points and annual variable costs.

According to this sensitivity analysis table, when annual variable costs are $5MM at 100% (and $4.5MM at 90% capacity, which is our case), a product price of $0.76 per pound is necessary to obtain a positive, albeit small, IRR of 2.11%. However, to reach a more acceptable IRR of at least 12%, a product price of $0.97 is necessary. At our current product price, annual variable costs would need to be reduced to $3.99MM to have a (barely) positive IRR. At the current product price, not even a 50% reduction in annual variable cost would yield a suitable IRR. This project has very high annual costs. Refer to Section 13 for the tables summarizing fixed and variable cost.

A simple balance on the ethylene and propylene sales, byproduct sales, cost of raw materials, and cost of utilities can be performed on a per-pound of ethylene and propylene basis to understand how variable costs affect profitability:

	Eth/Propylene	Byproducts	Raw Material	Utilities
$/lb of C2/C3	0.69	0.31	-0.29	-0.17
Total $/lb of C2/C3 prod:	0.54			

The cost of raw material and utilities equal 66.7% of the value of the ethylene and propylene product, and the byproducts generated in the process equal 44.9% of the value of the ethylene and propylene product. One way to increase the value of the process overall would be to reduce the amount of raw materials and utilities required in the process, as shown in the sensitivity analysis table above.

iii. Potential Adjustments for Increased Profitability

Despite the current process's failure to breakeven and generate profit, chemical recycling of plastic waste may still be a worthy process for investors to consider. There are several parts of our process that could be modified to reduce costs and make the process more economically viable.

In this process, there are several streams that have some valuable property that are not currently being exploited. These alternatives were not considered for the purposes of this project due to time constraints, but it would be worthwhile to investigate further if this plant were to be designed. The distillate from the C2-Splitter and depropanizer columns exit the condenser at roughly -30°F. These streams could be used to cool water so that it could be sold as a chilled water byproduct. Further, all of the streams that exit the separations process are sent to be stored in storage tanks at 30 psia. They each exit the column at fairly high pressure (ranging from 150 psia to 300 psia). As these gases move from high pressure to low pressure, they will expand. When a gas expands, it can be used to perform work. Gas expansion in a turbine can generate electricity. That would be an idea worth investigating for future development of this process.

There are also opportunities to reduce the amount of utilities used in the process. For example, in the depropanizer column, the two feed streams are fed at the same tray location. As discussed in Section 10, these feeds could be fed into the column at different locations to reduce the amount of cooling and heating duty needed in the condenser and reboiler of the column (see Section 10 for a detailed explanation of this reasoning). This would lower the amount of utilities required for the depropanizer column. However, this is only a small contribution to the utilities cost; the compressor in the refrigeration cycle requires $2MM worth of electricity annually, which is by far the greatest utility requirement in the process.

One drastic modification that could potentially turn this endeavor into a profitable one would be to do away with the separations and refrigeration processes and sell the steam-cracked product to a plant that is equipped to handle these costly separations. Petroleum and ethylene plants use similar separations processes to produce ethylene and propylene from naphtha and other hydrocarbon oils, but because they sell a greater amount of product, they are able to turn a profit.

The steam-cracked product from our process, which is comprised of the same light hydrocarbons found in natural gas, could be used as supplemental feedstock in plants that already produce ethylene and propylene. The utilities associated with the separations process in our project are extremely costly; the electricity for the compressor in the refrigeration cycle costs over $2MM per year, and accounts for almost half of the total variable cost. Eliminating these costs would save a large amount of money annually.

With this modification, ethylene and propylene would no longer be the products; rather, a light hydrocarbon oil would be the product. Price information for this light hydrocarbon oil would need to be determined to analyze the profitability of the process with this modification. Another consequence of this modification would be that some of the byproducts would no longer be produced, and we would lose on revenue opportunity there.

Removing the separations and refrigeration sections would also significantly reduce the total capital investment. The equipment cost for the separations and refrigeration process units is $10MM. This represents 78% of the total equipment cost. Getting rid of this equipment, would significantly reduce the total capital investment from $27.5MM to $17.5MM (and that's only considering the equipment itself—removing this section would also reduce the amount of land required for the plant, the cost of plant start-up, and other components of capital investment that depend on the bare module cost). With a lower total capital investment, it would be easier to breakeven in a shorter amount of time and to start generating profit.

iv. Summary

While the proposed process for chemical recycling of mixed plastic waste is not a profitable endeavor, the concept is still a worthy pursuit, as there are several possible modifications and alternatives to the existing process that could make the process a profitable one.

Section 17. Conclusions and Recommendation

The process described offers insight into a circular monomers' economy. 70 MT/day of high-density polyethylene, low-density polyethylene, polypropylene, and polystyrene are converted to 33,840 lb/day of 99% purity ethylene and 30,000 lb/day of 95.7% purity propylene. Pyrolytic oil, chilled water, and high-pressure steam are additionally produced for sale. The overall recovery is 41.4% by mass of the monomers originally in the plastic feedstock.

The innovative design combines plastic waste processing technology with established unsaturated hydrocarbon production techniques in a two-part cracking process. Notably, the byproducts of the cracking reactions provide a sufficient fuel source to meet the high energy demands of cracking chemistry, which has both economic and environmental benefits.

Economically, the process is not profitable, and we do not recommend investing in the process as it is currently modeled. The Internal Rate of Return (IRR) is -4.74%, the Net Present Value (NPV) is -$18.8MM, and the Return on Investment (ROI) in the third year of operation is -2.12%; it would not be worth investing in this project unless the IRR and ROI were much higher, around 12-15% at least. However, chemical recycling deserves to be considered as a viable recycling option; there are ways to make the process more profitable, and the environmental benefits of the process are important enough to warrant further development and consideration. Additionally, exploration into government subsidy for the environmental merits of the process may hold potential in achieving profit.

It is recommended that a pilot-scale facility is constructed to better understand and optimize the process, especially the rotary kiln. The true product distribution and function of the kiln, as well as the proposed method for purifying the fuel oil product, are It is recommended that a pilot-scale facility is constructed to better understand and optimize the process, especially the rotary kiln. The true product distribution and function of the kiln, as well as the proposed method for purifying the fuel oil product, are at this time theoretical. In scale-up, challenges will arise surrounding heat transfer in all stages of the process, given the high temperatures of the cracking reactions and low temperatures of the separations train.

Section 18. Acknowledgments

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Section 20. Appendix

Appendix A: Calculations

Rotary Kiln Pyrolysis Unit

Average density of waste = 58.9 lb/ft^3

Assume 80% empty volume to favor gas formation

19.7% of input not converted: average of 59.9% by weight non-gas in kiln

Feed rate = 6430 lb/hr, with 47.5-minute residence time = 5090 lb/47.5 minutes

(.599)(5090lb) = 3049 lb liquid = 51.8 ft^3

80% void fraction: **V = 259 ft^3**

L/D = 15: **L=2.8 ft; D = 42ft**

Find Angle Using the Manning Formula:

v = 0.0147 ft/s

Area for flow = 0.738 ft^2

Wetted perimeter = 2.04 ft

R_h = 0.738/2.04 = 0.362 ft

K = 1.49 (English Units)

n = 0.019 (Gauckler-Manning Coefficient for rough steel due to presence of char)

S = 0.0192 ft/ft (rotary kiln standard is 0.02-0.04 ft/ft)

Θ = 1.1^0

Gas generated = 5161 lb/hr = 4086 lb/47.5 min

V_{gas} = 259-51.8 = 207.2 ft^3

T = 1112 ^{0}F

Approximate molar mass of gas as 38.6 g/mol

N_{gen} = 48015 mol/47.5 min

P = nRT/V

P_{closed} = 8610 psia (!)

Thus, will use a pressure cap to operate at **73.5 psia**

C_p = f(t). Values of C_p for PE, PP, PS established as functions of temperature on a per-mol basis. Not per kg. Conversion is complex, thus approximate with:

C_p (polystyrene) = 1400 J / kg K
C_p(polyethylene) = 1900 J / kg K
C_p(polypropylene) = 1920 J / kg K
Average = 0.442 BTU/lb ^{0}F

Heating need in first section:

$$Q = H_{in} - H_{out}$$

H_{in} (approximate) = m C_p ΔT (of molten polymer) = 2.94 x 10^6 BTU/hr

H_{out} (from ASPEN) = 4.33 x 10^6 BTU/hr

Assuming 40% thermal efficiency **Q = 3.44 x 10^6 BTU/hr**

Pyrolysis Oil considered as:

Styrene: $C_8H_8 + 10\ O_2 \rightarrow 8\ CO_2 + 4\ H_2O$ ($-\Delta H_R$ = 4232.6 kJ/mol)

Toluene: $C_7H_8 + 9\ O_2 \rightarrow 7\ CO_2 + 4\ H_2O$ ($-\Delta H_R$ = 3909.7 kJ/mol)

Ethylbenzene: $C_8H_{10} + 10.5\ O_2 \rightarrow 8\ CO_2 + 5\ H_2O$ ($-\Delta H_R$ = 4564.5 kJ/mol)

$\Delta H_{C\ pyrolysis\ oil}$ = 3963 BTU/mol

Adiabatic flame temperature:

4181000 J = (8.213 J/mol K) * (+ 5)

T_2 = 8852^{0}F

Too high, thus will need to dilute with air. Assume that the pyrolysis temperature chamber is 2732 ^{0}F (1500^{0}C). This temperature is non-trivially selected due to the nature of insulating refractories.

4181000 J = (8.314 J/mol K) * (+ 5)

n_{air} = 28 mol

Thus 1 mol of pyrolysis oil combusts to 8 mol CO_2, 5 mol H_2O, and 28 mol air at 2732 ^{0}F.

Assume the air will cool to 1292^{0}F (700^0 C).

ΔH (using above with $n_{air} = 28$ and $T_1 = 700^0C$) = 2501 BTU gas available/mol combusted

Fuel requirement is therefore (using 100.8 g/mol mass of fuel oil): 306 lb/hr

-this is for the first 15.5 ft of the kiln, during which the heating is said to occur-

-consider the second 26.5 ft, during which the temperature need be maintained at 1112^0F-

Assume heat loss of 500 BTU/ hr ft^2

Area = $(\pi)(2.8\ ft)(26.5\ ft) = 233\ ft^2$

With again 40% efficiency, **Q = 2.24 x 10^5 BTU/hr**

With the same combustion temperature, oil demand is therefore: 19.9 lb/hr

Total Oil Requirement = 325.9 lb/hr

Castable thickness:

In a rough approximation, one dimensional heat transfer, $q_x" = k(\Delta T)/L$

The heat flux in the heating region is: (1.39×10^6 BTU/hr)/(π*2.8 ft*15.5ft)

= 1.31×10^4 BTU/hr ft^2

k = 10.4 BTU/h ft ^0F

ΔT (chamber to chamber) = 1620 ^0F

Suppose $\Delta T_{refractory}$ should be 1000^0F to prevent overheating in the reaction chamber and to protect the inner carbon steel

L = 0.7 ft = 8.4 inches.

Thus, the inner wall has a thickness of 0.25 in of Carbon Steel and 8.4 in of alumina oxide refractory.

Outerwall (assume same heat flux)

Now, ΔT (combustion chamber to outside) = 2532 (if kiln exterior is no more than 200^0F)

$\Delta T_{refractory} = 1500\ ^0F$

L = 1.2 ft = 14.4 in

The outer wall of the kiln will be 14.4 inches of alumina oxide refractory with 0.25 in of carbon steel exterior for support.

Solid/Liquid Splitter

The vessel needs to handle 1181 lb/hr of oil and 84 lb/hr of char. The density of the oil is an estimated 46.2 lb/ft^3. The vessel is assumed to be 60% full, and it is desired that it can contain up to 1 residence time cycle of kiln product (1000 lb). The volume required is thus 36.1 ft^3. Using an assumed aspect ratio of 5, the dimensions of the unit are found. 36.1 ft^3 = $(\pi/4)*(D^2)*(5D)$, which gives dimensions of **2.09 ft diameter and 10.5 ft length.**

There are two outlets of this vessel, one with liquid product and one with a slurry. The slurry is assumed to be the char and to have 15% of liquid in it. Thus, the liquid outlet flow rate is 1003 lb/hr, and the slurry is 262 lb/hr.

Costing:

$$C_P = F_M C_V + C_{PL}$$

$$F_M = 1 \text{(Carbon Steel)}$$

$$C_V = \exp(5.6336 + 0.4599 \ln(W) + 0.00582 (\ln(W))^2$$

$$C_{PL} = 2275 D^{0.2094}$$

$$C_{PL} = \$2655$$

$$C_V = \$7973$$

$$C_P = \$10{,}628$$

Plastic Extrusion Screw

The extrusion screw is simply a unit purchased from manufacturers. The desired capacity used for search is 3000 kg/hr. The full details on what is found are included in Appendix II. The cost, estimated from online, is $500,000.

The power requirement is estimated: It should be noted that in an extrusion screw, much of the heat generated is as a result from the friction between the plastic and the wall and viscous heating effects. A detailed analysis on the temperature profile and heating zones of the screw are not included.

PE: heat of melting = 287.6 kJ/kg. C_p = 1900 J / kg K. Melting point = 142^{o}C.
Heat Required: Assume PE flow is 2916 kg/hr * (.511) = 1490 kg/hr

Heat requirement = (1490 kg/hr)*((287.6 kJ/kg)+(1.9 kJ/kg K)(225 K)) = 1065499 kJ/hr = 295 kW

PP: heat of melting = 103.8 kJ/kg, C_p = 1920 J / kg K, melting point = 158^{0}C.

Assume PP flow is 2916 kg/hr * (.372) = 1084 kg/hr

Heat Requirement = (1084 kg/hr) * ((103.8 kJ/kg) + (1.92 kJ/ kg K)(225 K)) = 161 kW

Polystyrene: heat of fusion = 96.2 kJ/kg, C_p = 1400 J / kg K, melting point = 240^{0}C

Assume PS flow is (2916 kg/hr) * (.116) = 338 kg/hr

Heat Requirement = (338 kg/hr) * ((96.2 kJ/kg) + (1.2 kJ/kg K)(225K)) = 34 kW

Heat required for melting = 490 kW. This is primarily supplied by the drive force to the motor. 80% efficiency is assumed, and the demand is thus 612.5 kW = 821 hp.

The two models below are used to inform power requirement and economics:



SAT-X Series

Model	Diameter (mm)	Max. Speed (rpm)	Motor (kW)	Specific Torque (Nm/cm3)	Output (kg/hr)
SAT-X52	51.4	800	160	12	450-700
SAT-X65	62.4	800	280	12	700-1200
SAT-X75	71	600	355	13.1	800-1400
SAT-X95	93	600	750	12.6	1700-2600
SAT-X110	110	400	800	12.4	2200-3300
SAT-X130	130	400	1400	12.5	3000-4500
SAT-X175	175	300	2000	10.2	6000-8000

SK series

SK series divide the functions for conventional single-screw and developed each capability. In addition, it controlled them separately. Thus, it enjoys more freedom and fully performs the capability that an single-axis extruder has.

Features

- Pellet extrusion of PVC and PE
- It demonstrates excellent performance for film and sheet extrusion (PVC, PS, ABS), especially PVC's transparent sheet and two-axis drawing film.

SK extruder standard specifications

			SK90		SK115		SK135		SK150		SK200		SK/GTR		SK/PCM	
			1st layer	2nd layer	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Screw	Diameter	mm	90	80 100	115	100 115	135	125	150	135	200	170	GTR65 -110	GS100 -135	PCM30 -135	GS65 -200
Screw	L/D	-	22 , 25	12	22 , 25	12	22 , 25	12	22 , 25	12	22 , 25	12	22 , 25	12	22 , 25	12
Screw	Acceptance of bent	-	φ	-	φ	-	φ	-	φ	-	φ	-	φ	-	φ	-
Throughput rate		kg/h	200 - 400		300 - 600		400 - 800		500 - 1200		800 - 2500		10 - 30		10 - 30	

Bucket Elevators

The height of the bucket elevators estimated as 5 feet above the required height. For the elevator to the silos, this means that the height is 55 feet. For the elevator to section 001 and the extrusion screw, the height is estimated from summing the rotary kiln diameter and slant height and adding 10 feet for machinery and equipment beneath the kiln. This height is 16 feet.

For both elevators, the width of the buckets is estimated as 1 foot.

Costing:

$$C_P = 692\ W^{0.5}\ L^{0.57}$$

C_P (elevator 1) = \$23,534; C_P (elevator 2) = \$11,642

Power Requirement:

$$P = 0.02\ m\ (L^{0.63}) + 0.00182\ mL$$

P (elevator 1) = 0.626 hp; P (elevator 2) = 0.206 hp

Screw Feeder

Volumetric Feed Rate:

Assuming a 75% empty space due to packing, density is approximate as 78.5 lb/ ft^3:

$S = 6430$ lb/hr = 81.9 ft ft^3/ hr

Costing:

$C_P = 1094\ S^{0.22}$ = \$2883 (cost includes motor and belt drive)

Power Requirement:

$$P = 0.0146\ L\ (m)^{0.85}$$

m = 1.79 lb/s; L (approximated) = 40 ft; P = 0.958 hp

Feed Silo

Average shard density = 58.9 lb/ft^3

Daily processing capacity = 70 MT = 154324 lb; space demand is 2620 ft^3 for one day of plastic

Assume, due to packing, 75% empty space thus space demand is 3490 ft^3 per day.

Allow each silo to store three days' worth of material.

$V_{silo} = 10500\ ft^3$

Assume an aspect ratio of 3: $10500\ ft^3 = (\pi/4)*(D^2)*(3D)$

Diameter = 16.5 ft; Length = 49.5 ft

Costing: C_P: $646\ S^{0.46}$ = \$45,707

Blower

Sample given for B-101
Sizing:

$$k = 1.4;\ n_B = 0.75;\ P_B = 23\text{ hp}$$
$$\eta_m = 0.8 + 0.0319\ln(P_B) - 0.00182(\ln(P_B))^2$$
$$\eta_m = 0.882$$
$$P_C = P_B / \eta_m = 26.1\text{ hp}$$

Costing:

$$C_P = C_B F_M$$
$$F_M = 0.6\text{ (aluminum)}$$
$$C_B = \exp(7.0187 + 0.79\ln(P_C))$$
$$C_B = \$14{,}700$$
$$C_P = \$8{,}820$$

Steam Cracker

Calculating heat required

The heat required for the radiative section of the furnace is found by adding the heat required of the cracking reaction and the sensible heat required to heat the feed stream to the coil outlet temperature (COT).

The heat of cracking can be found from:

where *i* represents all the product components, *j* represents the reactant components, and is the mass flow rate. Using this equation, the heat of cracking was calculated to be 10.4 MM BTU/hr. The temperature dependent specific enthalpies of formation of components was acquired from NIST.

The sensible heat required to increase the temperature of the cracked gas (diluent steam and light gas) from the crossover temperature (XOT) to the COT is:

where is the mass flow rate of steam, , is the specific enthalpy of steam at the COT, is the specific enthalpy of steam at the XOT, is the mass flow rate of light gas, and is the average specific heat. The sensible heat was calculated to be 2.65 MM BTU/hr.

The process duty was calculated from:

The heat needed to preheat the process steam to XOT is found from:

where is the latent heat of vaporization of water and is the temperature of the water leaving the purge stream, and is the saturation temperature of water at atmospheric pressure. The heat needed to preheat the process steam is 3.04 MM BTU/hr.

The heat needed to preheat the boiler feed water is 13.09 MM BTU/hr and is found from:

The total heat requirement from the radiation section of the steam cracker is found from:

where a 21.5% heat loss is assumed.

Flue gas requirements

The following equations show the general method of calculating the flue gas and fuel requirements to satisfy .

Where is a fraction of radiation section duty that a specific fuel, *k*, will satisfy, is the specific enthalpy of flue gas leaving the firebox into the convection section, and is the specific enthalpy of the flue gas in the firebox. was determined from the following combustion reaction:

where *k* is methane, 10% excess air was assumed, and the lower heating value (LHV) is 21,433 BTU/lb. Through this combustion reaction, can be calculated:

A mass balance can be done to calculate the amount of fuel needed to supply amount of heat:

where β is 0.477.

Quench Tower

A tower diameter and height of 3.5 and 8 feet respectively is assumed. The tower would be made from carbon steel, which has a density of 490 lb/ft^3.

Transfer Line Exchanger

The heat duty of the TLE, or any heat exchanger, is determined from the desired sensible heat changer of the stream of interest. The heat duty can be calculated from the following equation:

where is the mass low rate of the stream, is the average specific heat capacity of the stream, and is the inlet and outlet temperature difference.

The calculated heat duty is then equated to an identical equation of the alternate stream passing through the heat exchanger. In the second case, either or is unknown and it must be solved for.

Once specified, the area of the heat exchanger can be calculated from its overall heat transfer coefficient U [BTU/ft^2-lb-hr], heat duty Q [BTU/hr], and log-mean temperature difference.

The velocity of the stream can calculated, or one can assume a value from 1-10ft/s, the cross-sectional area of the heat exchanger can be calculated from:

where is the density of the stream and is the velocity. A pipe inner diameter can be assumed and the number of tubes per pass in the HX can be found from:

Assume a tube length of 8ft, 12ft, 16ft, or 20ft and calculate the surface area of one tube and then the number of tube passes can be calculated.

Distillation Columns

Costing

Example: Demethanizer Column

$$C_p = F_M C_V + C_{PL}$$
$$F_M = 1$$
$$C_P = 190{,}083 + 25{,}236$$
$$C_P = \$215{,}318 \text{ at CE} = 567$$
$$C_P = \$227{,}850 \text{ at CE} = 600$$

$$C_V = \exp\{10.5449 - 0.4672\,[\ln(W)] + 0.0.05482[\ln(W)]^2\}$$
$$W = 69{,}955 \text{ lbs}$$
$$C_V = \$190{,}083$$

$$C_{PL} = 341*(D)^{0.63316}(L)^{0.80161}$$
$$D = 5.4 \text{ ft}$$
$$L = 57.5 \text{ ft}$$
$$C_{PL} = \$25{,}236$$

$$W = \pi\,(D_i + t_S)(L + 0.8D_i)t_{sp}\,\rho$$
$$D_i = 5.3 \text{ ft}$$
$$t_s = 1.567 \text{ in}$$
$$\rho = 490 \text{ lb/cuft}$$
$$W = 69{,}955 \text{ lbs}$$

$$P_d = \exp\{0.60608 + 0.91615[\ln(P_o)] + 0.0015655[\ln(Po)]^2\}$$
$$P_o = 535.3 \text{ psig}$$
$$P_d = 616 \text{ psig}$$

$$C_T = N_T F_{NT} F_{TT} F_{TM} C_{BT}$$
$$N_T = 15$$
$$F_{TT} = 1$$
$$F_{TM} = 1$$
$$C_T = \$18,853 \text{ at } CE = 567$$
$$C_T = \$19,950 \text{ at } CE = 600$$

$$F_{NT} = 2.251/0414N_T$$
$$F_{NT} = 1.22$$

$$C_{BT} = 468\exp(0.1482Di)$$
$$C_{BT} = 1,027$$

$$C_{TOT} = C_T + C_P$$
$$C_{TOT} = 19,950 + 227,850 = \$247,800$$

$$C_{BM} = C_{TOT} * F_{BM}$$
$$F_{BM} = 4.16$$
$$C_{BM} = \$1,030,848$$

Pumps

Sizing

Example: C2 Feed Pump

$$S = Q(H)^{0.5}$$
$$S = (7.06\text{ gal/min})*(477\text{ft})^{0.5}$$
$$S = 916\text{ (gpm)(ft)}^{0.5}$$

H taken from ASPEN report

Costing

$$C_P = F_T F_M C_B$$
$$F_M = 1 \text{ for cast iron}$$
$$F_T = 1$$
$$C_P = (1)(1)(4305) = \$4296 \text{ for CE} = 567$$
$$C_P = \$4{,}546 \text{ FOR CE} = 600$$

$$C_B = \exp[12.1656 - 1.144\text{lb}(S) + 0.0862(\ln(S))^2]$$
$$C_B = 4{,}305 \text{ for CE} = 567$$

Heat Exchangers

Condensers and reboilers were both modeled as U-tube heat exchangers.

Sizing

ASPEN provided heat transfer area required for each piece of equipment.

Costing

Example: Demethanizer Condenser

$$C_P = F_P F_M F_L C_B$$
$$C_P = 1.13*1*1*19{,}085$$
$$C_P = \$21{,}579 \text{ for CE} = 567$$
$$C_P = \$22{,}835 \text{ for CE} = 600$$

$$C_B = \exp[11.4185 - 0.9228\ln(A) + 0.09861(\ln(A))^2]$$
$$C_B = \$72{,}388$$

$$F_M = a + (A/100)^b$$

$$a = 0$$
$$b = 0$$
$$F_M = 1 \text{ for carbon steel/carbon steel}$$

$$F_L = 1 \text{ for 20 ft tube}$$

Storage Tanks

Sizing

Storage tanks were designed to allow for one hour's worth of storage of gas product. To determine the volume needed for one hour's worth of storage, the volumetric flowrate was determined and multiplied by the amount of time for storage (one hour). The storage tanks are kept at 70°F and 14.7 psia, and properties of the components were calculated at these conditions.

Example: Ethylene Product Storage Tank

Volume:

$$\rho_{ethylene} = 0.073 \text{ lbs/cuft at 70°F, 14.7 psia}$$
$$m_{ethylene} = 1410 \text{ lbs/hr}$$
$$v_{ethylene} = m_{ethylene} / \rho_{ethylene} = 19{,}316 \text{ cuft/hr}$$

Length and Diameter:

$$L = 59.0 \text{ ft}$$
$$L/D = 3$$
$$D = L/3$$
$$D = 19.7 \text{ ft}$$

Costing

Storage tanks were modeled as floating roof storage tanks because the contents of the tanks are all in gas form.

Example: Ethylene Storage Tank

$$C_p = 475*V^{0.507}$$

$$V = 144{,}494 \text{ gallons}$$

$$C_p = \$188{,}996 \text{ at CE} = 567$$

$$C_p = \$199{,}996 \text{ at CE} = 600$$

Compressors

Sizing

ASPEN provided sizing information for the compressor. See section 11 specification sheet for sizing information.

Costing

Example: Refrigeration Compressor

$$C_p = F_D F_M C_B$$

$$F_D = 1$$

$$F_M = 1$$

$$C_B = \$2{,}226{,}011$$

$$C_P = \$2{,}226{,}011 \text{ at CE} = 567$$

$$C_P = \$2{,}355{,}567 \text{ at CE} = 600$$

$$C_B = \exp\{9.1553+0.63[\ln(P_C)]\}$$

$$P_C = 5810 \text{ hp}$$

$$C_B = \$2{,}226{,}011$$

Flash Vessels

Sizing

Flash Vessels were modeled as vertical pressure vessels and sized assuming a 5-minute residence time. The volume needed for 5 minutes' worth of accumulation was calculated and an L/D aspect ratio of 3 was assumed to determine the dimensions of the vessels.

Example: Flash Vessel 1

$$\text{Volumetric flow rate} = 2{,}631 \text{ cuft/hr}$$

$$5 \text{ minutes of accumulation} = 219.25 \text{ cuft}$$

$$L = 13.6 \text{ ft}$$

$$D = 4.53 \text{ ft}$$

Costing

Example: Flash Vessel 1

$$C_P = F_M C_V + C_{PL}$$

$$F_M = 1 \text{ for carbon steel}$$

$$C_v = 120{,}685$$

$$C_{PL} = 410(D_i)^{0.73960}(L)^{0.70864}$$

$$C_P = \$128{,}614 \text{ for CE} = 567$$

$$C_P = 136{,}099 \text{ for CE} = 600$$

$$C_V = \exp\{7.1390 + 0.18255[\ln(W)] + 0.2297\,[\ln(W)]^2\}$$

$$C_V = \$120{,}685$$

Appendix B: MSDS Sheets

SAFETY DATA SHEET

Ethylene

Section 1. Identification

GHS product identifier : Ethylene

Chemical name : ethylene

Other means of identification : Ethene; Ethene (ethylene); impure; ethylene, pure

Product type : Liquefied gas

Product use : Synthetic/Analytical chemistry.

Synonym : Ethene; Ethene (ethylene); impure; ethylene, pure

SDS # : 001022

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE GASES - Category 1
GASES UNDER PRESSURE - Liquefied gas
SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE) (Narcotic effects) - Category 3

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : Extremely flammable gas.
May form explosive mixtures with air.
Contains gas under pressure; may explode if heated.
May cause frostbite.
May displace oxygen and cause rapid suffocation.
May cause drowsiness or dizziness.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Always keep container in upright position. Approach suspected leak area with caution.

Prevention : Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. Use only outdoors or in a well-ventilated area. Avoid breathing gas.

Response : IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER or physician if you feel unwell. Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.

Storage : Store locked up. Protect from sunlight. Store in a well-ventilated place.

Section 2. Hazards identification

Disposal : Dispose of contents and container in accordance with all local, regional, national and international regulations.

Hazards not otherwise classified : Liquid can cause burns similar to frostbite.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : ethylene

Other means of identification : Ethene; Ethene (ethylene); impure; ethylene, pure

Product code : 001022

CAS number/other identifiers

CAS number : 74-85-1

Ingredient name	%	CAS number
ethylene	100	74-85-1

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention. If necessary, call a poison center or physician. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. In case of contact with liquid, warm frozen tissues slowly with lukewarm water and get medical attention. Do not rub affected area. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : Remove victim to fresh air and keep at rest in a position comfortable for breathing. Get medical attention. If necessary, call a poison center or physician. Ingestion of liquid can cause burns similar to frostbite. If frostbite occurs, get medical attention. Never give anything by mouth to an unconscious person. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband. As this product rapidly becomes a gas when released, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Liquid can cause burns similar to frostbite.

Inhalation : Can cause central nervous system (CNS) depression. May cause drowsiness or dizziness.

Safety Data Sheet

Version 1.16 | SDS Number 300000000074
Revision Date 08/01/2016 | Print Date 08/04/2018

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Hydrogen
Chemical formula	:	$H2$
Synonyms	:	Hydrogen
Product Use Description	:	General Industrial
Manufacturer/Importer/Distributor	:	Versum Materials US, LLC 8555 South River Parkway Tempe, AZ 85284 Exporter EIN No.475632014 www.versummaterials.com
Telephone	:	(602)282-1000
Emergency telephone number (24h)	:	1-800-424-9300 (CHEMTREC) and (+1) 703-741-5970 (CHEMTREC)

2. HAZARDS IDENTIFICATION

GHS classification

Flammable gases - Category 1
Gases under pressure - Compressed gas.

GHS label elements

Hazard pictograms/symbols

Signal Word: Danger

Hazard Statements:

H220:Extremely flammable gas.

H280:Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.
May form explosive mixtures in air.
Burns with invisible flame.

Precautionary Statements:

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 :Eliminate all ignition sources if safe to do so.

Storage : P410+P403:Protect from sunlight. Store in a well-ventilated place.

Hazards not otherwise classified

Burns with an invisible flame.
Can ignite on contact with air.
High pressure gas.
Can cause rapid suffocation.
Extremely flammable.
May form explosive mixtures in air.
Immediate fire and explosion hazard exists when mixed with air at concentrations exceeding the lower flammability limit (LFL).
High concentrations that can cause rapid suffocation are within the flammable range and should not be entered.
Avoid breathing gas.
Self contained breathing apparatus (SCBA) may be required.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Components	CAS Number	Concentration (Volume)
Hydrogen	1333-74-0	100 %

Concentration is nominal. For the exact product composition, please refer to technical specifications.

4. FIRST AID MEASURES

General advice : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Eye contact : In case of direct contact with eyes, seek medical advice.

Skin contact : Adverse effects not expected from this product. IF exposed or concerned: Get medical advice/attention.

SAFETY DATA SHEET

Methane

Airgas
an Air Liquide company

Section 1. Identification

GHS product identifier : Methane

Chemical name : methane

Other means of identification : Methane or natural gas; Marsh gas; Methyl hydride; CH4; Fire Damp;

Product type : Gas.

Product use : Synthetic/Analytical chemistry.

Synonym : Methane or natural gas; Marsh gas; Methyl hydride; CH4; Fire Damp;

SDS # : 001033

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE GASES - Category 1
GASES UNDER PRESSURE - Compressed gas

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : Extremely flammable gas.
May form explosive mixtures with air.
Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Approach suspected leak area with caution.

Prevention : Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

Response : Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.

Storage : Protect from sunlight. Store in a well-ventilated place.

Disposal : Not applicable.

Hazards not otherwise classified : In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : methane

Other means of identification : Methane or natural gas; Marsh gas; Methyl hydride; CH4; Fire Damp;

Product code : 001033

CAS number/other identifiers

CAS number : 74-82-8

Ingredient name	%	CAS number
methane	100	74-82-8

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Wash contaminated skin with soap and water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

Specific treatments : No specific treatment.

Safety Data Sheet

Version 1.10 SDS Number 300000000118
Revision Date 08/01/2016 Print Date 08/04/2018

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Propylene
Chemical formula	:	C3H6
Synonyms	:	Propylene, Propene, APACHI® Gas, Methyl Ethylene
Product Use Description	:	General Industrial
Manufacturer/Importer/Distributor	:	Air Products and Chemicals, Inc 7201 Hamilton Blvd. Allentown, PA 18195-1501 GST No. 123600835 RT0001 QST No. 102753981 TQ0001
Telephone	:	1-610-481-4911 Corporate 1-800-345-3148 Chemicals Cust Serv 1-800-752-1597 Gases/Electronics Cust Serv
Emergency telephone number (24h)	:	800-523-9374 USA +1 610 481 7711 International

2. HAZARDS IDENTIFICATION

GHS classification

Flammable gases - Category 1
Gases under pressure - Liquefied gas.
Simple Asphyxiant

GHS label elements

Hazard pictograms/symbols

Signal Word: Danger

Hazard Statements:

H220:Extremely flammable gas.
H280:Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.
May form explosive mixtures in air.
May cause frostbite.

Precautionary Statements:

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 :Eliminate all ignition sources if safe to do so.

Storage : P403:Store in a well-ventilated place.

Hazards not otherwise classified

Can cause rapid suffocation.
Extremely flammable liquefied gas.
May form explosive mixtures in air.
Vapors may spread long distances and ignite.
Immediate fire and explosion hazard exists when mixed with air at concentrations exceeding the lower flammability limit (LFL).
High concentrations that can cause rapid suffocation are within the flammable range and should not be entered.
Avoid breathing gas.
Direct contact with liquid can cause frostbite.
Self contained breathing apparatus (SCBA) may be required.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Components	CAS Number	Concentration (Volume)
Propylene	115-07-1	100 %

4. FIRST AID MEASURES

General advice : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Eye contact : In the case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
Keep eye wide open while rinsing. Seek medical advice.

Skin contact : Wash frost-bitten areas with plenty of water. Do not remove clothing. Cover wound with sterile dressing.

SAFETY DATA SHEET

N-Butane

an Air Liquide company

Section 1. Identification

GHS product identifier : N-Butane

Chemical name : butane

Other means of identification : n-BUTANE; Methylethylmethane; Diethyl; Butyl hydride; normal-Butane; butane, pure

Product type : Gas.

Product use : Synthetic/Analytical chemistry.

Synonym : n-BUTANE; Methylethylmethane; Diethyl; Butyl hydride; normal-Butane; butane, pure

SDS # : 001007

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE GASES - Category 1
GASES UNDER PRESSURE - Liquefied gas

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : Extremely flammable gas.
May form explosive mixtures with air.
Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Always keep container in upright position. Approach suspected leak area with caution.

Prevention : Never Put cylinders into unventilated areas of passenger vehicles. Keep away from heat, sparks, open flames and hot surfaces. - No smoking. Use and store only outdoors or in a well ventilated place.

Response : Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.

Storage : Protect from sunlight. Store in a well-ventilated place.

Disposal : Not applicable.

Hazards not otherwise classified : In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : butane

Other means of identification : n-BUTANE; Methylethylmethane; Diethyl; Butyl hydride; normal-Butane; butane, pure

Product code : 001007

CAS number/other identifiers

CAS number : 106-97-8

Ingredient name	%	CAS number
N-Butane	100	106-97-8

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : No known significant effects or critical hazards.

Inhalation : No known significant effects or critical hazards.

Skin contact : No known significant effects or critical hazards.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

Specific treatments : No specific treatment.

SAFETY DATA SHEET

Styrene

Version 1.8 | Revision Date 2019-11-20

SECTION 1: Identification of the substance/mixture and of the company/undertaking

Product information

Product Name : Styrene
Material : 1037612, 1037607, 1037608, 1037609

Company : Chevron Phillips Chemical Company LP
10001 Six Pines Drive
The Woodlands, TX 77380

Emergency telephone:

Health:
866.442.9628 (North America)
1.832.813.4984 (International)
Transport:
CHEMTREC 800.424.9300 or 703.527.3887(int'l)
Asia: CHEMWATCH (+612 9186 1132) China: 0532 8388 9090
EUROPE: BIG +32.14.584545 (phone) or +32.14583516 (telefax)
Mexico CHEMTREC 01-800-681-9531 (24 hours)
South America SOS-Cotec Inside Brazil: 0800.111.767 Outside Brazil: +55.19.3467.1600
Argentina: +(54)-1159839431

Responsible Department : Product Safety and Toxicology Group
E-mail address : SDS@CPChem.com
Website : www.CPChem.com

SECTION 2: Hazards identification

Classification of the substance or mixture
This product has been classified in accordance with the hazard communication standard 29 CFR 1910.1200; the SDS and labels contain all the information as required by the standard.

Classification : Flammable liquids, Category 3
Skin irritation, Category 2
Eye irritation, Category 2A
Specific target organ toxicity - repeated exposure, Category 1, Inhalation, Auditory organs
Aspiration hazard, Category 1

Labeling

Symbol(s) :

Signal Word : Danger

Hazard Statements : H226: Flammable liquid and vapor.
H304: May be fatal if swallowed and enters airways.
H315: Causes skin irritation.
H319: Causes serious eye irritation.
H372: Causes damage to organs (Auditory organs) through prolonged or repeated exposure if inhaled.

Precautionary Statements : **Prevention:**
P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233 Keep container tightly closed.
P240 Ground/bond container and receiving equipment.
P241 Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242 Use only non-sparking tools.
P243 Take precautionary measures against static discharge.
P260 Do not breathe dust/fume/gas/mist/vapor/spray.
P264 Wash skin thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.
P271 Use only outdoors or in a well-ventilated area.
P280 Wear protective gloves/ eye protection/ face protection.
Response:
P301 + P310 IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353 IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P312 IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.
P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P314 Get medical advice/ attention if you feel unwell.
P331 Do NOT induce vomiting.
P332 + P313 If skin irritation occurs: Get medical advice/ attention.
P337 + P313 If eye irritation persists: Get medical advice/ attention.
P362 Take off contaminated clothing and wash before reuse.
P370 + P378 In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
Storage:
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P403 + P235 Store in a well-ventilated place. Keep cool.
P405 Store locked up.
Disposal:
P501 Dispose of contents/ container to an approved waste disposal plant.

ThermoFisher
SCIENTIFIC

SAFETY DATA SHEET

Creation Date 11-Jun-2009 **Revision Date** 17-Jan-2018 **Revision Number** 4

1. Identification

Product Name	**Toluene**
Cat No. :	**T326F-1GAL; T326P-4; T326S-20; T326S-20LC**
CAS-No	108-88-3
Synonyms	Tol; Methylbenzene
Recommended Use	Laboratory chemicals.
Uses advised against	Not for food, drug, pesticide or biocidal product use

Details of the supplier of the safety data sheet

Company
Fisher Scientific
One Reagent Lane
Fair Lawn, NJ 07410
Tel: (201) 796-7100

Emergency Telephone Number
CHEMTREC®, Inside the USA: 800-424-9300
CHEMTREC®, Outside the USA: 001-703-527-3887

2. Hazard(s) identification

Classification
This chemical is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200)

Flammable liquids	Category 2
Skin Corrosion/irritation	Category 2
Serious Eye Damage/Eye Irritation	Category 2
Reproductive Toxicity	Category 2
Specific target organ toxicity (single exposure)	Category 3
Target Organs - Respiratory system, Central nervous system (CNS).	
Specific target organ toxicity - (repeated exposure)	Category 2
Target Organs - Kidney, Liver, spleen, Blood.	
Aspiration Toxicity	Category 1

Label Elements

Signal Word
Danger

Hazard Statements
Highly flammable liquid and vapor
May be fatal if swallowed and enters airways
Causes skin irritation
Causes serious eye irritation
May cause respiratory irritation
May cause drowsiness or dizziness

Suspected of damaging the unborn child
Causes damage to organs through prolonged or repeated exposure

Precautionary Statements
Prevention
Obtain special instructions before use
Do not handle until all safety precautions have been read and understood
Use personal protective equipment as required
Wash face, hands and any exposed skin thoroughly after handling
Wear eye/face protection
Do not breathe dust/fume/gas/mist/vapors/spray
Do not eat, drink or smoke when using this product
Use only outdoors or in a well-ventilated area
Keep away from heat/sparks/open flames/hot surfaces. - No smoking
Keep container tightly closed
Ground/bond container and receiving equipment
Use explosion-proof electrical/ventilating/lighting/equipment
Use only non-sparking tools
Take precautionary measures against static discharge
Keep cool
Response
IF exposed or concerned: Get medical attention/advice
Inhalation
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing
Skin
If skin irritation occurs: Get medical advice/attention
IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower
Wash contaminated clothing before reuse
Eyes
IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing
If eye irritation persists: Get medical advice/attention
Ingestion
IF SWALLOWED: Immediately call a POISON CENTER or doctor/physician
Do NOT induce vomiting
Fire
In case of fire: Use CO2, dry chemical, or foam for extinction
Storage
Store locked up
Store in a well-ventilated place. Keep container tightly closed
Disposal
Dispose of contents/container to an approved waste disposal plant
Hazards not otherwise classified (HNOC)

WARNING. Reproductive Harm - https://www.p65warnings.ca.gov/.

3. Composition/Information on Ingredients

Component	CAS-No	Weight %
Toluene	108-88-3	>95

Thermo Fisher SCIENTIFIC

SAFETY DATA SHEET

Creation Date 06-Aug-2010 **Revision Date** 17-Jan-2018 **Revision Number** 6

1. Identification

Product Name	**Ethylbenzene**
Cat No. :	**O2751-1**
CAS-No	100-41-4
Synonyms	Ethylbenzol; Phenylethane
Recommended Use	Laboratory chemicals.
Uses advised against	Not for food, drug, pesticide or biocidal product use

Details of the supplier of the safety data sheet

Company
Fisher Scientific
One Reagent Lane
Fair Lawn, NJ 07410
Tel: (201) 796-7100

Emergency Telephone Number
CHEMTREC®, Inside the USA: 800-424-9300
CHEMTREC®, Outside the USA: 001-703-527-3887

2. Hazard(s) identification

Classification
This chemical is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200)

Flammable liquids	Category 2
Acute Inhalation Toxicity - Vapors	Category 4
Carcinogenicity	Category 2
Specific target organ toxicity (single exposure)	Category 3
Target Organs - Respiratory system, Central nervous system (CNS).	
Specific target organ toxicity - (repeated exposure)	Category 2
Aspiration Toxicity	Category 1

Label Elements

Signal Word
Danger

Hazard Statements
Highly flammable liquid and vapor
May be fatal if swallowed and enters airways
Harmful if inhaled
May cause respiratory irritation
May cause drowsiness or dizziness
Suspected of causing cancer
May cause damage to organs through prolonged or repeated exposure

Precautionary Statements
Prevention
Obtain special instructions before use
Do not handle until all safety precautions have been read and understood
Use personal protective equipment as required
Use only outdoors or in a well-ventilated area
Do not breathe dust/fume/gas/mist/vapors/spray
Keep away from heat/sparks/open flames/hot surfaces. - No smoking
Keep container tightly closed
Ground/bond container and receiving equipment
Use explosion-proof electrical/ventilating/lighting/equipment
Use only non-sparking tools
Take precautionary measures against static discharge
Keep cool
Response
IF exposed or concerned: Get medical attention/advice
Inhalation
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing
Skin
IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower
Ingestion
IF SWALLOWED: Immediately call a POISON CENTER or doctor/physician
Do NOT induce vomiting
Fire
In case of fire: Use CO2, dry chemical, or foam for extinction
Storage
Store locked up
Store in a well-ventilated place. Keep container tightly closed
Disposal
Dispose of contents/container to an approved waste disposal plant
Hazards not otherwise classified (HNOC)
Harmful to aquatic life with long lasting effects
WARNING. Cancer - https://www.p65warnings.ca.gov/.

3. Composition/Information on Ingredients

Component	CAS-No	Weight %
Ethylbenzene	100-41-4	>95

4. First-aid measures

General Advice If symptoms persist, call a physician.

Eye Contact Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes. Get medical attention.

Skin Contact Wash off immediately with plenty of water for at least 15 minutes. Obtain medical attention.

Appendix C: ASPEN Report

Section 200: Compressor Blocks and Streams

LOCK: C-201 MODEL: COMPR

INLET STREAM: CG-1

OUTLET STREAM: CG-2

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	455.679	455.679	0.00000
MASS(LB/HR)	5163.00	5163.00	0.00000
ENTHALPY(BTU/HR)	31255.0	970025.	-0.967779

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	15175.0	LB/HR
PRODUCT STREAMS CO2E	15175.0	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

PRESSURE CHANGE PSI	115.000
ISENTROPIC EFFICIENCY	0.81000
MECHANICAL EFFICIENCY	1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT	HP	368.950
BRAKE HORSEPOWER REQUIREMENT	HP	368.950
NET WORK REQUIRED	HP	368.950
POWER LOSSES	HP	0.0
ISENTROPIC HORSEPOWER REQUIREMENT	HP	298.850
CALCULATED OUTLET PRES	PSIA	158.500
CALCULATED OUTLET TEMP	F	324.318
ISENTROPIC TEMPERATURE	F	284.025
EFFICIENCY (POLYTR/ISENTR) USED		0.81000
OUTLET VAPOR FRACTION		1.00000
HEAD DEVELOPED,	FT-LBF/LB	114,608.
MECHANICAL EFFICIENCY USED		1.00000
INLET HEAT CAPACITY RATIO		1.30401
INLET VOLUMETRIC FLOW RATE ,	CUFT/HR	62,906.5
OUTLET VOLUMETRIC FLOW RATE,	CUFT/HR	24,288.8
INLET COMPRESSIBILITY FACTOR		0.99986
OUTLET COMPRESSIBILITY FACTOR		1.00418
AV. ISENT. VOL. EXPONENT		1.28690
AV. ISENT. TEMP EXPONENT		1.28183
AV. ACTUAL VOL. EXPONENT		1.35871
AV. ACTUAL TEMP EXPONENT		1.35258

BLOCK: C-202 MODEL: COMPR

INLET STREAM: CG-3

OUTLET STREAM: CG-4

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	455.679	455.679	0.00000
MASS(LB/HR)	5163.00	5163.00	0.00000
ENTHALPY(BTU/HR)	533809.	978008.	-0.454188

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 15175.0 LB/HR

PRODUCT STREAMS CO2E 15175.0 LB/HR

NET STREAMS CO2E PRODUCTION 0.00000 LB/HR

UTILITIES CO2E PRODUCTION 0.00000 LB/HR

TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

PRESSURE CHANGE PSI 115.000

ISENTROPIC EFFICIENCY 0.81000

MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP 174.577

BRAKE HORSEPOWER REQUIREMENT HP 174.577

NET WORK REQUIRED HP 174.577

POWER LOSSES HP 0.0

ISENTROPIC HORSEPOWER REQUIREMENT HP	141.407
CALCULATED OUTLET PRES PSIA	273.500
CALCULATED OUTLET TEMP F	326.707
ISENTROPIC TEMPERATURE F	307.839
EFFICIENCY (POLYTR/ISENTR) USED	0.81000
OUTLET VAPOR FRACTION	1.00000
HEAD DEVELOPED, FT-LBF/LB	54,229.4
MECHANICAL EFFICIENCY USED	1.00000
INLET HEAT CAPACITY RATIO	1.28050
INLET VOLUMETRIC FLOW RATE , CUFT/HR	21,167.5
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR	14,162.9
INLET COMPRESSIBILITY FACTOR	1.00308
OUTLET COMPRESSIBILITY FACTOR	1.00731
AV. ISENT. VOL. EXPONENT	1.27956
AV. ISENT. TEMP EXPONENT	1.26772
AV. ACTUAL VOL. EXPONENT	1.35763
AV. ACTUAL TEMP EXPONENT	1.34354

BLOCK: C-203 MODEL: COMPR

INLET STREAM: CG-5

OUTLET STREAM: CG-6

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	455.679	455.679	0.00000
MASS(LB/HR)	5163.00	5163.00	0.00000

ENTHALPY(BTU/HR) 539151. 820758. -0.343106

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 15175.0 LB/HR

PRODUCT STREAMS CO2E 15175.0 LB/HR

NET STREAMS CO2E PRODUCTION 0.00000 LB/HR

UTILITIES CO2E PRODUCTION 0.00000 LB/HR

TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

PRESSURE CHANGE PSI 115.000

ISENTROPIC EFFICIENCY 0.81000

MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP 110.676

BRAKE HORSEPOWER REQUIREMENT HP 110.676

NET WORK REQUIRED HP 110.676

POWER LOSSES HP 0.0

ISENTROPIC HORSEPOWER REQUIREMENT HP 89.6474

CALCULATED OUTLET PRES PSIA 388.500

CALCULATED OUTLET TEMP F 292.152

ISENTROPIC TEMPERATURE F 280.070

EFFICIENCY (POLYTR/ISENTR) USED 0.81000

OUTLET VAPOR FRACTION 1.00000

HEAD DEVELOPED, FT-LBF/LB 34,379.6

MECHANICAL EFFICIENCY USED 1.00000

INLET HEAT CAPACITY RATIO	1.28483
INLET VOLUMETRIC FLOW RATE , CUFT/HR	12,339.8
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR	9,556.64
INLET COMPRESSIBILITY FACTOR	1.00552
OUTLET COMPRESSIBILITY FACTOR	1.00987
AV. ISENT. VOL. EXPONENT	1.29011
AV. ISENT. TEMP EXPONENT	1.27116
AV. ACTUAL VOL. EXPONENT	1.37322
AV. ACTUAL TEMP EXPONENT	1.35039

BLOCK: C-204 MODEL: COMPR

INLET STREAM: CG-7

OUTLET STREAM: CG-8

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	455.679	455.679	0.00000
MASS(LB/HR)	5163.00	5163.00	0.00000
ENTHALPY(BTU/HR)	386804.	665985.	-0.419200

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	15175.0	LB/HR
PRODUCT STREAMS CO2E	15175.0	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

PRESSURE CHANGE PSI	171.000
ISENTROPIC EFFICIENCY	0.81000
MECHANICAL EFFICIENCY	1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP	109.722
BRAKE HORSEPOWER REQUIREMENT HP	109.722
NET WORK REQUIRED HP	109.722
POWER LOSSES HP	0.0
ISENTROPIC HORSEPOWER REQUIREMENT HP	88.8751
CALCULATED OUTLET PRES PSIA	559.500
CALCULATED OUTLET TEMP F	258.307
ISENTROPIC TEMPERATURE F	246.232
EFFICIENCY (POLYTR/ISENTR) USED	0.81000
OUTLET VAPOR FRACTION	1.00000
HEAD DEVELOPED, FT-LBF/LB	34,083.4
MECHANICAL EFFICIENCY USED	1.00000
INLET HEAT CAPACITY RATIO	1.29956
INLET VOLUMETRIC FLOW RATE , CUFT/HR	8,258.40
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR	6,359.03
INLET COMPRESSIBILITY FACTOR	1.00657
OUTLET COMPRESSIBILITY FACTOR	1.01336
AV. ISENT. VOL. EXPONENT	1.30828
AV. ISENT. TEMP EXPONENT	1.27962
AV. ACTUAL VOL. EXPONENT	1.39561

AV. ACTUAL TEMP EXPONENT	1.36058

CG-1

STREAM ID	CG-1
FROM :	----
TO :	C-201

SUBSTREAM: MIXED

PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
HYDROGEN	301.1092
METHANE	37.8364
MONOXIDE	0.1071
ETHANE	7.2831
ETHENE	70.5431
PROPANE	1.1792
PROPENE	30.5841
BUTANE	7.0368
WATER	0.0
TOTAL FLOW:	
LBMOL/HR	455.6790
LB/HR	5163.0000
CUFT/HR	6.2907+04
STATE VARIABLES:	
TEMP F	100.0000
PRES PSIA	43.5000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	68.5900
BTU/LB	6.0537
BTU/HR	3.1255+04
ENTROPY:	
BTU/LBMOL-R	-7.6582
BTU/LB-R	-0.6759
DENSITY:	
LBMOL/CUFT	7.2437-03
LB/CUFT	8.2074-02
AVG MW	11.3303

CG-2

STREAM ID	CG-2
FROM :	C-201
TO :	HX-203

SUBSTREAM: MIXED

PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
HYDROGEN	301.1092
METHANE	37.8364
MONOXIDE	0.1071
ETHANE	7.2831
ETHENE	70.5431

PROPANE	1.1792
PROPENE	30.5841
BUTANE	7.0368
WATER	0.0
TOTAL FLOW:	
LBMOL/HR	455.6790
LB/HR	5163.0000
CUFT/HR	2.4289+04
STATE VARIABLES:	
TEMP F	324.3175
PRES PSIA	158.5000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	2128.7462
BTU/LB	187.8801
BTU/HR	9.7002+05
ENTROPY:	
BTU/LBMOL-R	-7.1457
BTU/LB-R	-0.6307
DENSITY:	
LBMOL/CUFT	1.8761-02
LB/CUFT	0.2126
AVG MW	11.3303

CG-3

STREAM ID	CG-3
FROM :	HX-203
TO :	C-202

SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
HYDROGEN	301.1092
METHANE	37.8364
MONOXIDE	0.1071
ETHANE	7.2831
ETHENE	70.5431
PROPANE	1.1792
PROPENE	30.5841
BUTANE	7.0368
WATER	0.0
TOTAL FLOW:	
LBMOL/HR	455.6790
LB/HR	5163.0000
CUFT/HR	2.1168+04
STATE VARIABLES:	
TEMP F	224.3176
PRES PSIA	158.5000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	1171.4576
BTU/LB	103.3912
BTU/HR	5.3381+05
ENTROPY:	

BTU/LBMOL-R -8.4512
BTU/LB-R -0.7459
DENSITY:
LBMOL/CUFT 2.1527-02
LB/CUFT 0.2439
AVG MW 11.3303

CG-4

STREAM ID CG-4
FROM : C-202
TO : HX-204

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LBMOL/HR
HYDROGEN 301.1092
METHANE 37.8364
MONOXIDE 0.1071
ETHANE 7.2831
ETHENE 70.5431
PROPANE 1.1792
PROPENE 30.5841
BUTANE 7.0368
WATER 0.0
TOTAL FLOW:
LBMOL/HR 455.6790
LB/HR 5163.0000
CUFT/HR 1.4163+04
STATE VARIABLES:
TEMP F 326.7066
PRES PSIA 273.5000
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0
ENTHALPY:
BTU/LBMOL 2146.2655
BTU/LB 189.4263
BTU/HR 9.7801+05
ENTROPY:
BTU/LBMOL-R -8.2128
BTU/LB-R -0.7249
DENSITY:
LBMOL/CUFT 3.2174-02
LB/CUFT 0.3645
AVG MW 11.3303

CG-5

STREAM ID CG-5
FROM : HX-204
TO : C-203

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LBMOL/HR
HYDROGEN 301.1092
METHANE 37.8364

MONOXIDE	0.1071
ETHANE	7.2831
ETHENE	70.5431
PROPANE	1.1792
PROPENE	30.5841
BUTANE	7.0368
WATER	0.0
TOTAL FLOW:	
LBMOL/HR	455.6790
LB/HR	5163.0000
CUFT/HR	1.2340+04
STATE VARIABLES:	
TEMP F	226.7066
PRES PSIA	273.5000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	1183.1812
BTU/LB	104.4259
BTU/HR	5.3915+05
ENTROPY:	
BTU/LBMOL-R	-9.5220
BTU/LB-R	-0.8404
DENSITY:	
LBMOL/CUFT	3.6927-02
LB/CUFT	0.4184
AVG MW	11.3303

CG-6

STREAM ID	CG-6
FROM :	C-203
TO :	HX-205

SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
HYDROGEN	301.1092
METHANE	37.8364
MONOXIDE	0.1071
ETHANE	7.2831
ETHENE	70.5431
PROPANE	1.1792
PROPENE	30.5841
BUTANE	7.0368
WATER	0.0
TOTAL FLOW:	
LBMOL/HR	455.6790
LB/HR	5163.0000
CUFT/HR	9556.6392
STATE VARIABLES:	
TEMP F	292.1519
PRES PSIA	388.5000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	1801.1761

BTU/LB 158.9692
BTU/HR 8.2076+05
ENTROPY:
BTU/LBMOL-R -9.3646
BTU/LB-R -0.8265
DENSITY:
LBMOL/CUFT 4.7682-02
LB/CUFT 0.5403
AVG MW 11.3303

CG-7

STREAM ID CG-7
FROM : HX-205
TO : C-204

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LBMOL/HR
HYDROGEN 301.1092
METHANE 37.8364
MONOXIDE 0.1071
ETHANE 7.2831
ETHENE 70.5431
PROPANE 1.1792
PROPENE 30.5841
BUTANE 7.0368
WATER 0.0
TOTAL FLOW:
LBMOL/HR 455.6790
LB/HR 5163.0000
CUFT/HR 8258.4021
STATE VARIABLES:
TEMP F 192.1519
PRES PSIA 388.5000
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0
ENTHALPY:
BTU/LBMOL 848.8522
BTU/LB 74.9185
BTU/HR 3.8680+05
ENTROPY:
BTU/LBMOL-R -10.7230
BTU/LB-R -0.9464
DENSITY:
LBMOL/CUFT 5.5178-02
LB/CUFT 0.6252
AVG MW 11.3303

CG-8

STREAM ID CG-8
FROM : C-204
TO : HX-206

SUBSTREAM: MIXED
PHASE: VAPOR

COMPONENTS: LBMOL/HR

HYDROGEN	301.1092
METHANE	37.8364
MONOXIDE	0.1071
ETHANE	7.2831
ETHENE	70.5431
PROPANE	1.1792
PROPENE	30.5841
BUTANE	7.0368
WATER	0.0

TOTAL FLOW:

LBMOL/HR	455.6790
LB/HR	5163.0000
CUFT/HR	6359.0251

STATE VARIABLES:

TEMP F	258.3075
PRES PSIA	559.5000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0

ENTHALPY:

BTU/LBMOL	1461.5228
BTU/LB	128.9919
BTU/HR	6.6599+05

ENTROPY:

BTU/LBMOL-R	-10.5595
BTU/LB-R	-0.9320

DENSITY:

LBMOL/CUFT	7.1659-02
LB/CUFT	0.8119

AVG MW 11.3303

CG-9

STREAM ID	CG-9
FROM :	HX-206
TO :	----

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LBMOL/HR

HYDROGEN	301.1092
METHANE	37.8364
MONOXIDE	0.1071
ETHANE	7.2831
ETHENE	70.5431
PROPANE	1.1792
PROPENE	30.5841
BUTANE	7.0368
WATER	0.0

TOTAL FLOW:

LBMOL/HR	455.6790
LB/HR	5163.0000
CUFT/HR	5292.0409

STATE VARIABLES:

TEMP F	142.3075
PRES PSIA	559.5000
VFRAC	1.0000
LFRAC	0.0

SFRAC	0.0	BTU/LBMOL-R	-12.2194
ENTHALPY:		BTU/LB-R	-1.0785
BTU/LBMOL	368.0489	DENSITY:	
BTU/LB	32.4835	LBMOL/CUFT	8.6106-02
BTU/HR	1.6771+05	LB/CUFT	0.9756
ENTROPY:		AVG MW	11.3303

Section 200: Intercooler blocks and streams

BLOCK: HX-203 MODEL: HEATX

```
-----------------------------
 HOT SIDE:
 ---------
 INLET STREAM:            CG-2
 OUTLET STREAM:           CG-3
 PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
 COLD SIDE:
 ----------
 INLET STREAM:            CW-IN3
 OUTLET STREAM:           CW-OUT3
 PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

                 ***  MASS AND ENERGY BALANCE  ***
                           IN           OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          983.009       983.009       0.00000
    MASS(LB/HR   )          14663.0       14663.0       0.00000
    ENTHALPY(BTU/HR  )     -0.645271E+08  -0.645271E+08   0.230929E-15

                 ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E            15175.0      LB/HR
  PRODUCT STREAMS CO2E         15175.0      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
  UTILITIES CO2E PRODUCTION     0.00000     LB/HR
  TOTAL CO2E PRODUCTION         0.00000     LB/HR

                    ***  INPUT DATA  ***
```

FLASH SPECS FOR HOT SIDE:

TWO PHASE FLASH

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:

TWO PHASE FLASH

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FLOW DIRECTION AND SPECIFICATION:

COUNTERCURRENT HEAT EXCHANGER

SPECIFIED HOT TEMP CHANGE

SPECIFIED VALUE F 100.0000

LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:

HOT SIDE PRESSURE DROP PSI 0.0000

COLD SIDE PRESSURE DROP PSI 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:

OVERALL COEFFICIENT BTU/HR-SQFT-R 80.0000

*** OVERALL RESULTS ***

STREAMS:

```
              --------------------------------------
              |                             |
CG-2    ----->|           HOT               |-----> CG-3
T=  3.2432D+02 |                            |    T=  2.2432D+02
```

```
P=  1.5850D+02  |                                  |      P=  1.5850D+02
V=  1.0000D+00  |                                  |      V=  1.0000D+00
             |                               |
CW-OUT3   <-----|              COLD              |<----- CW-IN3
T=  1.1981D+02  |                                  |      T=  8.0000D+01
P=  1.4696D+01  |                                  |      P=  1.4696D+01
V=  0.0000D+00  |                                  |      V=  0.0000D+00
             ------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY          BTU/HR           436216.3269
  CALCULATED (REQUIRED) AREA     SQFT                  31.5791
  ACTUAL EXCHANGER AREA         SQFT                  47.2562
  PER CENT OVER-DESIGN                               49.6440

HEAT TRANSFER COEFFICIENT:
  AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R          80.0000
  UA (DIRTY)                   BTU/HR-R           2526.3297

LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                              1.0000
  LMTD (CORRECTED)              F                  172.6680
  NUMBER OF SHELLS IN SERIES                           1

PRESSURE DROP:
  HOTSIDE, TOTAL              PSI                  0.0000
  COLDSIDE, TOTAL              PSI                  0.0000

HEATX COLD-TQCU HX-203   TQCURV INLET
-------------------------------------
```

PRESSURE PROFILE: CONSTANT2

PRESSURE DROP: 0.0 PSI

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	14.6959	119.8091	0.0
2.0772+04	14.6959	117.9127	0.0
4.1544+04	14.6959	116.0163	0.0
6.2317+04	14.6959	114.1199	0.0
8.3089+04	14.6959	112.2234	0.0
1.0386+05	14.6959	110.3270	0.0
1.2463+05	14.6959	108.4307	0.0
1.4541+05	14.6959	106.5343	0.0
1.6618+05	14.6959	104.6381	0.0
1.8695+05	14.6959	102.7419	0.0
2.0772+05	14.6959	100.8458	0.0
2.2849+05	14.6959	98.9499	0.0
2.4927+05	14.6959	97.0540	0.0
2.7004+05	14.6959	95.1583	0.0
2.9081+05	14.6959	93.2628	0.0

```
! 3.1158+05 !    14.6959 !    91.3675 !     0.0    !
! 3.3236+05 !    14.6959 !    89.4723 !     0.0    !
! 3.5313+05 !    14.6959 !    87.5774 !     0.0    !
! 3.7390+05 !    14.6959 !    85.6826 !     0.0    !
! 3.9467+05 !    14.6959 !    83.7882 !     0.0    !
!------------+------------+------------+------------!
! 4.1544+05 !    14.6959 !    81.8939 !     0.0    !
! 4.3622+05 !    14.6959 !    80.0000 !     0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR HX-203   TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0        PSI
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

-----------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC     !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! BTU/HR    ! PSIA      ! F         !           !
!           !           !           !           !
!============!============!============!============!
!    0.0    !  158.5000 !  324.3175 !    1.0000 !
! 2.0772+04 !  158.5000 !  319.6650 !    1.0000 !
! 4.1544+04 !  158.5000 !  315.0022 !    1.0000 !
! 6.2317+04 !  158.5000 !  310.3290 !    1.0000 !
! 8.3089+04 !  158.5000 !  305.6452 !    1.0000 !
!------------+------------+------------+------------!
```

```
! 1.0386+05 !   158.5000 !   300.9509 !     1.0000 !
! 1.2463+05 !   158.5000 !   296.2459 !     1.0000 !
! 1.4541+05 !   158.5000 !   291.5300 !     1.0000 !
! 1.6618+05 !   158.5000 !   286.8033 !     1.0000 !
! 1.8695+05 !   158.5000 !   282.0656 !     1.0000 !
!------------+------------+------------+------------!
! 2.0772+05 !   158.5000 !   277.3167 !     1.0000 !
! 2.2849+05 !   158.5000 !   272.5567 !     1.0000 !
! 2.4927+05 !   158.5000 !   267.7854 !     1.0000 !
! 2.7004+05 !   158.5000 !   263.0027 !     1.0000 !
! 2.9081+05 !   158.5000 !   258.2084 !     1.0000 !
!------------+------------+------------+------------!
! 3.1158+05 !   158.5000 !   253.4026 !     1.0000 !
! 3.3236+05 !   158.5000 !   248.5850 !     1.0000 !
! 3.5313+05 !   158.5000 !   243.7556 !     1.0000 !
! 3.7390+05 !   158.5000 !   238.9143 !     1.0000 !
! 3.9467+05 !   158.5000 !   234.0609 !     1.0000 !
!------------+------------+------------+------------!
! 4.1544+05 !   158.5000 !   229.1953 !     1.0000 !
! 4.3622+05 !   158.5000 !   224.3176 !     1.0000 !
-----------------------------------------------------


BLOCK:  HX-204   MODEL: HEATX
-----------------------------
  HOT SIDE:
  ---------
  INLET STREAM:             CG-4
  OUTLET STREAM:            CG-5
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
  COLD SIDE:
```

INLET STREAM: CW-IN4

OUTLET STREAM: CW-OUT4

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

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

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	*985.896*	*985.896*	*0.00000*
MASS(LB/HR)	*14715.0*	*14715.0*	*0.00000*
ENTHALPY(BTU/HR)	*-0.648777E+08*	*-0.648777E+08*	*0.114840E-15*

**** CO2 EQUIVALENT SUMMARY ****

FEED STREAMS CO2E	*15175.0*	*LB/HR*
PRODUCT STREAMS CO2E	*15175.0*	*LB/HR*
NET STREAMS CO2E PRODUCTION	*0.00000*	*LB/HR*
UTILITIES CO2E PRODUCTION	*0.00000*	*LB/HR*
TOTAL CO2E PRODUCTION	*0.00000*	*LB/HR*

**** INPUT DATA ****

FLASH SPECS FOR HOT SIDE:

TWO PHASE FLASH

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:

TWO PHASE FLASH

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

```
FLOW DIRECTION AND SPECIFICATION:
  COUNTERCURRENT   HEAT EXCHANGER
  SPECIFIED HOT TEMP CHANGE
  SPECIFIED VALUE              F                 100.0000
  LMTD CORRECTION FACTOR                           1.00000

PRESSURE SPECIFICATION:
  HOT  SIDE PRESSURE DROP       PSI                0.0000
  COLD SIDE PRESSURE DROP       PSI                0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
  OVERALL COEFFICIENT          BTU/HR-SQFT-R         80.0000

                    ***  OVERALL RESULTS  ***

STREAMS:
               -------------------------------------
               |                                   |
CG-4      ----->|              HOT               |-----> CG-5
T=  3.2671D+02  |                                |       T=  2.2671D+02
P=  2.7350D+02  |                                |       P=  2.7350D+02
V=  1.0000D+00  |                                |       V=  1.0000D+00
               |                                   |
CW-OUT4   <-----|              COLD              |<----- CW-IN4
T=  1.1983D+02  |                                |       T=  8.0000D+01
P=  1.4696D+01  |                                |       P=  1.4696D+01
V=  0.0000D+00  |                                |       V=  0.0000D+00
               -------------------------------------
```

DUTY AND AREA:

CALCULATED HEAT DUTY BTU/HR 438857.3039

CALCULATED (REQUIRED) AREA SQFT 31.3343

ACTUAL EXCHANGER AREA SQFT 231.4625

PER CENT OVER-DESIGN 638.6875

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY) BTU/HR-SQFT-R 80.0000

UA (DIRTY) BTU/HR-R 2506.7434

LOG-MEAN TEMPERATURE DIFFERENCE:

LMTD CORRECTION FACTOR 1.0000

LMTD (CORRECTED) F 175.0707

NUMBER OF SHELLS IN SERIES 1

PRESSURE DROP:

HOTSIDE, TOTAL PSI 0.0000

COLDSIDE, TOTAL PSI 0.0000

HEATX COLD-TQCU HX-204 TQCURV INLET

PRESSURE PROFILE: CONSTANT2

PRESSURE DROP: 0.0 PSI

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

--

! DUTY ! PRES ! TEMP ! VFRAC !

! ! ! ! !

! ! ! ! !

! ! ! ! !

BTU/HR	PSIA	F	
0.0	14.6959	119.8321	0.0
2.0898+04	14.6959	117.9346	0.0
4.1796+04	14.6959	116.0371	0.0
6.2694+04	14.6959	114.1396	0.0
8.3592+04	14.6959	112.2421	0.0
1.0449+05	14.6959	110.3446	0.0
1.2539+05	14.6959	108.4471	0.0
1.4629+05	14.6959	106.5497	0.0
1.6718+05	14.6959	104.6523	0.0
1.8808+05	14.6959	102.7550	0.0
2.0898+05	14.6959	100.8579	0.0
2.2988+05	14.6959	98.9608	0.0
2.5078+05	14.6959	97.0639	0.0
2.7167+05	14.6959	95.1671	0.0
2.9257+05	14.6959	93.2705	0.0
3.1347+05	14.6959	91.3740	0.0
3.3437+05	14.6959	89.4778	0.0
3.5527+05	14.6959	87.5817	0.0
3.7616+05	14.6959	85.6859	0.0
3.9706+05	14.6959	83.7904	0.0
4.1796+05	14.6959	81.8950	0.0
4.3886+05	14.6959	80.0000	0.0

HEATX HOT-TQCUR HX-204   TQCURV INLET

```
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0        PSI
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE


-----------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC     !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! BTU/HR    ! PSIA      ! F         !           !
!           !           !           !           !
!============!============!============!============!
!    0.0    !  273.5000 !  326.7066 !    1.0000 !
! 2.0898+04 !  273.5000 !  322.0500 !    1.0000 !
! 4.1796+04 !  273.5000 !  317.3835 !    1.0000 !
! 6.2694+04 !  273.5000 !  312.7068 !    1.0000 !
! 8.3592+04 !  273.5000 !  308.0201 !    1.0000 !
!------------+------------+------------+------------!
! 1.0449+05 !  273.5000 !  303.3230 !    1.0000 !
! 1.2539+05 !  273.5000 !  298.6157 !    1.0000 !
! 1.4629+05 !  273.5000 !  293.8979 !    1.0000 !
! 1.6718+05 !  273.5000 !  289.1697 !    1.0000 !
! 1.8808+05 !  273.5000 !  284.4308 !    1.0000 !
!------------+------------+------------+------------!
! 2.0898+05 !  273.5000 !  279.6813 !    1.0000 !
! 2.2988+05 !  273.5000 !  274.9210 !    1.0000 !
! 2.5078+05 !  273.5000 !  270.1499 !    1.0000 !
```

```
!  2.7167+05 !   273.5000 !   265.3678 !     1.0000 !
!  2.9257+05 !   273.5000 !   260.5747 !     1.0000 !
!------------+------------+------------+------------!
!  3.1347+05 !   273.5000 !   255.7705 !     1.0000 !
!  3.3437+05 !   273.5000 !   250.9551 !     1.0000 !
!  3.5527+05 !   273.5000 !   246.1283 !     1.0000 !
!  3.7616+05 !   273.5000 !   241.2902 !     1.0000 !
!  3.9706+05 !   273.5000 !   236.4406 !     1.0000 !
!------------+------------+------------+------------!
!  4.1796+05 !   273.5000 !   231.5794 !     1.0000 !
!  4.3886+05 !   273.5000 !   226.7066 !     1.0000 !
-----------------------------------------------------

BLOCK:  HX-205   MODEL: HEATX
-----------------------------
 HOT SIDE:
 ---------
 INLET STREAM:             CG-6
 OUTLET STREAM:            CG-7
 PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
 COLD SIDE:
 ----------
 INLET STREAM:             CW-IN5
 OUTLET STREAM:            CW-OUT5
 PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

                 ***  MASS AND ENERGY BALANCE   ***
                            IN            OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          967.744        967.744        0.00000
```

MASS(LB/HR) 14388.0 14388.0 0.00000
ENTHALPY(BTU/HR) -0.627804E+08 -0.627804E+08 0.00000

**** CO2 EQUIVALENT SUMMARY ****

FEED STREAMS CO2E 15175.0 LB/HR
PRODUCT STREAMS CO2E 15175.0 LB/HR
NET STREAMS CO2E PRODUCTION 0.00000 LB/HR
UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2E PRODUCTION 0.00000 LB/HR

**** INPUT DATA ****

FLASH SPECS FOR HOT SIDE:
TWO PHASE FLASH
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:
TWO PHASE FLASH
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLOW DIRECTION AND SPECIFICATION:
COUNTERCURRENT HEAT EXCHANGER
SPECIFIED HOT TEMP CHANGE
SPECIFIED VALUE F 100.0000
LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:
HOT SIDE PRESSURE DROP PSI 0.0000

COLD SIDE PRESSURE DROP PSI 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:

OVERALL COEFFICIENT BTU/HR-SQFT-R 80.0000

**** OVERALL RESULTS ****

STREAMS:

```
             --------------------------------------
             |                           |
CG-6     ----->|          HOT           |-----> CG-7
T=  2.9215D+02  |                        |     T=  1.9215D+02
P=  3.8850D+02  |                        |     P=  3.8850D+02
V=  1.0000D+00  |                        |     V=  1.0000D+00
             |                           |
CW-OUT5  <-----|          COLD          |<----- CW-IN5
T=  1.2078D+02  |                        |     T=  8.0000D+01
P=  1.4696D+01  |                        |     P=  1.4696D+01
V=  0.0000D+00  |                        |     V=  0.0000D+00
             --------------------------------------
```

DUTY AND AREA:

CALCULATED HEAT DUTY	BTU/HR	433954.0386
CALCULATED (REQUIRED) AREA	SQFT	38.8363
ACTUAL EXCHANGER AREA	SQFT	158.5375
PER CENT OVER-DESIGN		308.2204

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY)	BTU/HR-SQFT-R	80.0000
UA (DIRTY)	BTU/HR-R	3106.9004

LOG-MEAN TEMPERATURE DIFFERENCE:

LMTD CORRECTION FACTOR 1.0000

LMTD (CORRECTED) F 139.6743

NUMBER OF SHELLS IN SERIES 1

PRESSURE DROP:

HOTSIDE, TOTAL PSI 0.0000

COLDSIDE, TOTAL PSI 0.0000

HEATX COLD-TQCU HX-205 TQCURV INLET

PRESSURE PROFILE: CONSTANT2

PRESSURE DROP: 0.0 PSI

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	14.6959	120.7836	0.0
2.0664+04	14.6959	118.8408	0.0
4.1329+04	14.6959	116.8980	0.0
6.1993+04	14.6959	114.9552	0.0
8.2658+04	14.6959	113.0123	0.0

```
! 1.0332+05 !   14.6959 !  111.0695 !    0.0    !
! 1.2399+05 !   14.6959 !  109.1267 !    0.0    !
! 1.4465+05 !   14.6959 !  107.1840 !    0.0    !
! 1.6532+05 !   14.6959 !  105.2413 !    0.0    !
! 1.8598+05 !   14.6959 !  103.2987 !    0.0    !
!-----------+-----------+-----------+-----------!
! 2.0664+05 !   14.6959 !  101.3562 !    0.0    !
! 2.2731+05 !   14.6959 !   99.4138 !    0.0    !
! 2.4797+05 !   14.6959 !   97.4715 !    0.0    !
! 2.6864+05 !   14.6959 !   95.5294 !    0.0    !
! 2.8930+05 !   14.6959 !   93.5875 !    0.0    !
!-----------+-----------+-----------+-----------!
! 3.0997+05 !   14.6959 !   91.6457 !    0.0    !
! 3.3063+05 !   14.6959 !   89.7042 !    0.0    !
! 3.5130+05 !   14.6959 !   87.7628 !    0.0    !
! 3.7196+05 !   14.6959 !   85.8217 !    0.0    !
! 3.9263+05 !   14.6959 !   83.8809 !    0.0    !
!-----------+-----------+-----------+-----------!
! 4.1329+05 !   14.6959 !   81.9403 !    0.0    !
! 4.3395+05 !   14.6959 !   80.0000 !    0.0    !
-------------------------------------------------

HEATX HOT-TQCUR HX-205   TQCURV INLET
------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0       PSI
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

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

```
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
! BTU/HR     ! PSIA       ! F          !            !
!            !            !            !            !
!============!============!============!============!
!    0.0     !  388.5000  !  292.1519  !    1.0000  !
! 2.0664+04  !  388.5000  !  287.4937  !    1.0000  !
! 4.1329+04  !  388.5000  !  282.8255  !    1.0000  !
! 6.1993+04  !  388.5000  !  278.1473  !    1.0000  !
! 8.2658+04  !  388.5000  !  273.4590  !    1.0000  !
!------------+------------+------------+------------!
! 1.0332+05  !  388.5000  !  268.7606  !    1.0000  !
! 1.2399+05  !  388.5000  !  264.0521  !    1.0000  !
! 1.4465+05  !  388.5000  !  259.3332  !    1.0000  !
! 1.6532+05  !  388.5000  !  254.6040  !    1.0000  !
! 1.8598+05  !  388.5000  !  249.8644  !    1.0000  !
!------------+------------+------------+------------!
! 2.0664+05  !  388.5000  !  245.1143  !    1.0000  !
! 2.2731+05  !  388.5000  !  240.3536  !    1.0000  !
! 2.4797+05  !  388.5000  !  235.5823  !    1.0000  !
! 2.6864+05  !  388.5000  !  230.8003  !    1.0000  !
! 2.8930+05  !  388.5000  !  226.0076  !    1.0000  !
!------------+------------+------------+------------!
! 3.0997+05  !  388.5000  !  221.2040  !    1.0000  !
! 3.3063+05  !  388.5000  !  216.3896  !    1.0000  !
! 3.5130+05  !  388.5000  !  211.5642  !    1.0000  !
! 3.7196+05  !  388.5000  !  206.7278  !    1.0000  !
! 3.9263+05  !  388.5000  !  201.8803  !    1.0000  !
!------------+------------+------------+------------!
```

! 4.1329+05 ! 388.5000 ! 197.0217 ! 1.0000 !

! 4.3395+05 ! 388.5000 ! 192.1519 ! 1.0000 !

--

BLOCK: HX-206 MODEL: HEATX

HOT SIDE:

INLET STREAM: CG-8

OUTLET STREAM: CG-9

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

COLD SIDE:

INLET STREAM: CW-IN6

OUTLET STREAM: CW-OUT6

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

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

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	1044.07	1044.07	0.00000
MASS(LB/HR)	15763.0	15763.0	0.00000
ENTHALPY(BTU/HR)	-0.724150E+08	-0.724150E+08	0.205774E-15

**** CO2 EQUIVALENT SUMMARY ****

FEED STREAMS CO2E 15175.0 LB/HR

PRODUCT STREAMS CO2E 15175.0 LB/HR

NET STREAMS CO2E PRODUCTION 0.00000 LB/HR

UTILITIES CO2E PRODUCTION 0.00000 LB/HR

TOTAL CO2E PRODUCTION 0.00000 LB/HR

**** INPUT DATA ****

FLASH SPECS FOR HOT SIDE:

TWO PHASE FLASH

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:

TWO PHASE FLASH

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FLOW DIRECTION AND SPECIFICATION:

COUNTERCURRENT HEAT EXCHANGER

SPECIFIED HOT TEMP CHANGE

SPECIFIED VALUE F 116.0000

LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:

HOT SIDE PRESSURE DROP PSI 0.0000

COLD SIDE PRESSURE DROP PSI 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:

OVERALL COEFFICIENT BTU/HR-SQFT-R 80.0000

**** OVERALL RESULTS ****

STREAMS:

```
             |                              |
CG-8     ----->|            HOT             |-----> CG-9
T=  2.5831D+02  |                            |      T=  1.4231D+02
P=  5.5950D+02  |                            |      P=  5.5950D+02
V=  1.0000D+00  |                            |      V=  1.0000D+00
             |                              |
CW-OUT6   <-----|            COLD            |<----- CW-IN6
T=  1.2075D+02  |                            |      T=  8.0000D+01
P=  1.4696D+01  |                            |      P=  1.4696D+01
V=  0.0000D+00  |                            |      V=  0.0000D+00
             -------------------------------------
```

DUTY AND AREA:

CALCULATED HEAT DUTY	*BTU/HR*	*498273.0938*
CALCULATED (REQUIRED) AREA	*SQFT*	*65.5513*
ACTUAL EXCHANGER AREA	*SQFT*	*84.3000*
PER CENT OVER-DESIGN		*28.6015*

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY)	*BTU/HR-SQFT-R*	*80.0000*
UA (DIRTY)	*BTU/HR-R*	*5244.1069*

LOG-MEAN TEMPERATURE DIFFERENCE:

LMTD CORRECTION FACTOR		*1.0000*
LMTD (CORRECTED)	*F*	*95.0158*
NUMBER OF SHELLS IN SERIES		*1*

PRESSURE DROP:

HOTSIDE, TOTAL	*PSI*	*0.0000*
COLDSIDE, TOTAL	*PSI*	*0.0000*

HEATX COLD-TQCU HX-206   TQCURV INLET

PRESSURE PROFILE: CONSTANT2

PRESSURE DROP: 0.0   PSI

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

DUTY	PRES	TEMP	VFRAC
BTU/HR	PSIA	F	
0.0	14.6959	120.7539	0.0
2.3727+04	14.6959	118.8126	0.0
4.7455+04	14.6959	116.8712	0.0
7.1182+04	14.6959	114.9297	0.0
9.4909+04	14.6959	112.9883	0.0
1.1864+05	14.6959	111.0469	0.0
1.4236+05	14.6959	109.1055	0.0
1.6609+05	14.6959	107.1642	0.0
1.8982+05	14.6959	105.2229	0.0
2.1355+05	14.6959	103.2817	0.0
2.3727+05	14.6959	101.3406	0.0
2.6100+05	14.6959	99.3997	0.0
2.8473+05	14.6959	97.4588	0.0

```
! 3.0845+05 !    14.6959 !    95.5181 !     0.0    !
! 3.3218+05 !    14.6959 !    93.5776 !     0.0    !
!------------+------------+------------+------------!
! 3.5591+05 !    14.6959 !    91.6372 !     0.0    !
! 3.7964+05 !    14.6959 !    89.6971 !     0.0    !
! 4.0336+05 !    14.6959 !    87.7572 !     0.0    !
! 4.2709+05 !    14.6959 !    85.8175 !     0.0    !
! 4.5082+05 !    14.6959 !    83.8781 !     0.0    !
!------------+------------+------------+------------!
! 4.7455+05 !    14.6959 !    81.9389 !     0.0    !
! 4.9827+05 !    14.6959 !    80.0000 !     0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR HX-206   TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0         PSI
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

-----------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC      !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! BTU/HR    ! PSIA      ! F         !           !
!           !           !           !           !
!============!============!============!============!
!     0.0    !   559.5000 !   258.3075 !     1.0000 !
! 2.3727+04 !   559.5000 !   252.9138 !     1.0000 !
! 4.7455+04 !   559.5000 !   247.5075 !     1.0000 !
```

7.1182+04	559.5000	242.0884	1.0000
9.4909+04	559.5000	236.6565	1.0000
1.1864+05	559.5000	231.2117	1.0000
1.4236+05	559.5000	225.7539	1.0000
1.6609+05	559.5000	220.2831	1.0000
1.8982+05	559.5000	214.7993	1.0000
2.1355+05	559.5000	209.3023	1.0000
2.3727+05	559.5000	203.7921	1.0000
2.6100+05	559.5000	198.2688	1.0000
2.8473+05	559.5000	192.7323	1.0000
3.0845+05	559.5000	187.1825	1.0000
3.3218+05	559.5000	181.6194	1.0000
3.5591+05	559.5000	176.0431	1.0000
3.7964+05	559.5000	170.4535	1.0000
4.0336+05	559.5000	164.8507	1.0000
4.2709+05	559.5000	159.2346	1.0000
4.5082+05	559.5000	153.6054	1.0000
4.7455+05	559.5000	147.9630	1.0000
4.9827+05	559.5000	142.3075	1.0000

CW-IN3

STREAM ID CW-IN3

FROM : ----

TO : HX-203

SUBSTREAM: MIXED

PHASE: LIQUID

COMPONENTS: LBMOL/HR

HYDROGEN	0.0
METHANE	0.0
MONOXIDE	0.0
ETHANE	0.0
ETHENE	0.0
PROPANE	0.0
PROPENE	0.0
BUTANE	0.0
WATER	527.3301

TOTAL FLOW:

LBMOL/HR	527.3301
LB/HR	9500.0000
CUFT/HR	153.3488

STATE VARIABLES:

TEMP F	80.0000
PRES PSIA	14.6959
VFRAC	0.0
LFRAC	1.0000
SFRAC	0.0

ENTHALPY:

BTU/LBMOL	-1.2421+05
BTU/LB	-6894.4368
BTU/HR	-6.5497+07

ENTROPY:

BTU/LBMOL-R	-40.7945
BTU/LB-R	-2.2644

DENSITY:

LBMOL/CUFT	3.4388
LB/CUFT	61.9503

AVG MW 18.0153

CW-OUT3

STREAM ID CW-OUT3

FROM : HX-203

TO : ----

SUBSTREAM: MIXED

PHASE: LIQUID

COMPONENTS: LBMOL/HR

HYDROGEN	0.0
METHANE	0.0
MONOXIDE	0.0
ETHANE	0.0
ETHENE	0.0
PROPANE	0.0
PROPENE	0.0

BUTANE 0.0
WATER 527.3301
TOTAL FLOW:
LBMOL/HR 527.3301
LB/HR 9500.0000
CUFT/HR 156.7670
STATE VARIABLES:
TEMP F 119.8091
PRES PSIA 14.6959
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2338+05
BTU/LB -6848.5193
BTU/HR -6.5061+07
ENTROPY:
BTU/LBMOL-R -39.3155
BTU/LB-R -2.1823
DENSITY:
LBMOL/CUFT 3.3638
LB/CUFT 60.5995
AVG MW 18.0153

CW-IN4

STREAM ID CW-IN4
FROM : ----
TO : HX-204

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
HYDROGEN 0.0
METHANE 0.0
MONOXIDE 0.0
ETHANE 0.0
ETHENE 0.0
PROPANE 0.0
PROPENE 0.0
BUTANE 0.0
WATER 530.2166
TOTAL FLOW:
LBMOL/HR 530.2166
LB/HR 9552.0000
CUFT/HR 154.1882
STATE VARIABLES:
TEMP F 80.0000
PRES PSIA 14.6959
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2421+05
BTU/LB -6894.4368
BTU/HR -6.5856+07
ENTROPY:
BTU/LBMOL-R -40.7945
BTU/LB-R -2.2644

DENSITY:
LBMOL/CUFT 3.4388
LB/CUFT 61.9503
AVG MW 18.0153

CW-OUT4

STREAM ID CW-OUT4
FROM : HX-204
TO : ----

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
HYDROGEN 0.0
METHANE 0.0
MONOXIDE 0.0
ETHANE 0.0
ETHENE 0.0
PROPANE 0.0
PROPENE 0.0
BUTANE 0.0
WATER 530.2166
TOTAL FLOW:
LBMOL/HR 530.2166
LB/HR 9552.0000
CUFT/HR 157.6272
STATE VARIABLES:
TEMP F 119.8321
PRES PSIA 14.6959
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2338+05
BTU/LB -6848.4927
BTU/HR -6.5417+07
ENTROPY:
BTU/LBMOL-R -39.3147
BTU/LB-R -2.1823
DENSITY:
LBMOL/CUFT 3.3637
LB/CUFT 60.5987
AVG MW 18.0153

CW-IN5

STREAM ID CW-IN5
FROM : ----
TO : HX-205

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
HYDROGEN 0.0
METHANE 0.0
MONOXIDE 0.0
ETHANE 0.0

ETHENE 0.0
PROPANE 0.0
PROPENE 0.0
BUTANE 0.0
WATER 512.0653
TOTAL FLOW:
LBMOL/HR 512.0653
LB/HR 9225.0000
CUFT/HR 148.9098
STATE VARIABLES:
TEMP F 80.0000
PRES PSIA 14.6959
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2421+05
BTU/LB -6894.4368
BTU/HR -6.3601+07
ENTROPY:
BTU/LBMOL-R -40.7945
BTU/LB-R -2.2644
DENSITY:
LBMOL/CUFT 3.4388
LB/CUFT 61.9503
AVG MW 18.0153

CW-OUT5

STREAM ID CW-OUT5
FROM : HX-205
TO : ----

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
HYDROGEN 0.0
METHANE 0.0
MONOXIDE 0.0
ETHANE 0.0
ETHENE 0.0
PROPANE 0.0
PROPENE 0.0
BUTANE 0.0
WATER 512.0653
TOTAL FLOW:
LBMOL/HR 512.0653
LB/HR 9225.0000
CUFT/HR 152.3132
STATE VARIABLES:
TEMP F 120.7836
PRES PSIA 14.6959
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2336+05
BTU/LB -6847.3957
BTU/HR -6.3167+07

ENTROPY:
BTU/LBMOL-R -39.2806
BTU/LB-R -2.1804
DENSITY:
LBMOL/CUFT 3.3619
LB/CUFT 60.5660
AVG MW 18.0153

CW-IN6

STREAM ID CW-IN6
FROM : ----
TO : HX-206

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
HYDROGEN 0.0
METHANE 0.0
MONOXIDE 0.0
ETHANE 0.0
ETHENE 0.0
PROPANE 0.0
PROPENE 0.0
BUTANE 0.0
WATER 588.3894
TOTAL FLOW:
LBMOL/HR 588.3894
LB/HR 1.0600+04
CUFT/HR 171.1050
STATE VARIABLES:
TEMP F 80.0000
PRES PSIA 14.6959
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2421+05
BTU/LB -6894.4368
BTU/HR -7.3081+07
ENTROPY:
BTU/LBMOL-R -40.7945
BTU/LB-R -2.2644
DENSITY:
LBMOL/CUFT 3.4388
LB/CUFT 61.9503
AVG MW 18.0153

CW-OUT6

STREAM ID CW-OUT6
FROM : HX-206
TO : ----

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
HYDROGEN 0.0

METHANE	0.0
MONOXIDE	0.0
ETHANE	0.0
ETHENE	0.0
PROPANE	0.0
PROPENE	0.0
BUTANE	0.0
WATER	588.3894
TOTAL FLOW:	
LBMOL/HR	588.3894
LB/HR	1.0600+04
CUFT/HR	175.0128
STATE VARIABLES:	
TEMP F	120.7539
PRES PSIA	14.6959

VFRAC	0.0
LFRAC	1.0000
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.2336+05
BTU/LB	-6847.4299
BTU/HR	-7.2583+07
ENTROPY:	
BTU/LBMOL-R	-39.2817
BTU/LB-R	-2.1805
DENSITY:	
LBMOL/CUFT	3.3620
LB/CUFT	60.5670
AVG MW	18.0153

Section 200: Pump blocks and streams

BLOCK: P-201 MODEL: PUMP

INLET STREAM: BW-1

OUTLET STREAM: BW-2

PROPERTY OPTION SET: STEAM-TA ASME STEAM TABLE EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	13443.0	13443.0	0.00000
MASS(LB/HR)	242180.	242180.	0.00000
ENTHALPY(BTU/HR)	-0.161924E+10	-0.161885E+10	-0.239884E-03

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 LB/HR

PRODUCT STREAMS CO2E 0.00000 LB/HR

NET STREAMS CO2E PRODUCTION 0.00000 LB/HR

UTILITIES CO2E PRODUCTION 0.00000 LB/HR

TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***

PRESSURE CHANGE PSI 420.000

PUMP EFFICIENCY 0.81000

DRIVER EFFICIENCY 0.81000

FLASH SPECIFICATIONS:

LIQUID PHASE CALCULATION

NO FLASH PERFORMED

MAXIMUM NUMBER OF ITERATIONS 30

TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE CUFT/HR	4,048.18
PRESSURE CHANGE PSI	420.000
NPSH AVAILABLE FT-LBF/LB	120.361
FLUID POWER HP	123.653
BRAKE POWER HP	152.658
ELECTRICITY KW	140.540
PUMP EFFICIENCY USED	0.81000
NET WORK REQUIRED HP	188.467
HEAD DEVELOPED FT-LBF/LB	1,010.96

BLOCK: P-202 MODEL: PUMP

INLET STREAM: SW-2

OUTLET STREAM: SW-3

PROPERTY OPTION SET: STEAM-TA ASME STEAM TABLE EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	10295.7	10295.7	0.00000
MASS(LB/HR)	185480.	185480.	0.00000
ENTHALPY(BTU/HR)	-0.126276E+10	-0.126274E+10	-0.135040E-04

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 LB/HR

PRODUCT STREAMS CO2E 0.00000 LB/HR

NET STREAMS CO2E PRODUCTION 0.00000 LB/HR

UTILITIES CO2E PRODUCTION 0.00000 LB/HR

TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***

PRESSURE CHANGE PSI	25.0000
PUMP EFFICIENCY	0.81000
DRIVER EFFICIENCY	0.81000
HYDRAULIC STATIC HEAD FT-LBF/LB	8.00000

FLASH SPECIFICATIONS:

LIQUID PHASE CALCULATION

NO FLASH PERFORMED

MAXIMUM NUMBER OF ITERATIONS	30
TOLERANCE	0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE CUFT/HR	2,985.66
PRESSURE CHANGE PSI	25.0000
NPSH AVAILABLE FT-LBF/LB	87.5189
FLUID POWER HP	5.42847
BRAKE POWER HP	6.70182
ELECTRICITY KW	6.16981
PUMP EFFICIENCY USED	0.81000
NET WORK REQUIRED HP	8.27385
HEAD DEVELOPED FT-LBF/LB	57.9490

BLOCK: P-203 MODEL: PUMP

INLET STREAM: REC-1

OUTLET STREAM: PS-1

PROPERTY OPTION SET: STEAM-TA ASME STEAM TABLE EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	114.680	114.680	0.00000
MASS(LB/HR)	2066.00	2066.00	0.00000
ENTHALPY(BTU/HR)	-0.140037E+08	-0.140033E+08	-0.283979E-04

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 LB/HR

PRODUCT STREAMS CO2E 0.00000 LB/HR

NET STREAMS CO2E PRODUCTION 0.00000 LB/HR

UTILITIES CO2E PRODUCTION 0.00000 LB/HR

TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***

PRESSURE CHANGE PSI 52.0000

PUMP EFFICIENCY 0.81000

DRIVER EFFICIENCY 0.81000

FLASH SPECIFICATIONS:

LIQUID PHASE CALCULATION

NO FLASH PERFORMED

MAXIMUM NUMBER OF ITERATIONS 30

TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE CUFT/HR 33.4752

PRESSURE CHANGE PSI 52.0000

NPSH AVAILABLE FT-LBF/LB	59.0516
FLUID POWER HP	0.12660
BRAKE POWER HP	0.15629
ELECTRICITY KW	0.14389
PUMP EFFICIENCY USED	0.81000
NET WORK REQUIRED HP	0.19295
HEAD DEVELOPED FT-LBF/LB	121.327

BW-1 BW-2 PS-1 REC-1 SW-2

STREAM ID	BW-1	BW-2	PS-1	REC-1	SW-2
FROM :	----	P-201	P-203	----	----
TO :	P-201	----	----	P-203	P-202
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
WATER	1.3443+04	1.3443+04	114.6804	114.6804	1.0296+04
TOTAL FLOW:					
LBMOL/HR	1.3443+04	1.3443+04	114.6804	114.6804	1.0296+04
LB/HR	2.4218+05	2.4218+05	2066.0000	2066.0000	1.8548+05
CUFT/HR	4048.1762	4043.4331	33.4703	33.4752	2985.6609
STATE VARIABLES:					
TEMP F	212.0000	212.6674	120.0596	120.0000	90.0000
PRES PSIA	64.6959	484.6959	79.0000	27.0000	35.0000
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0

ENTHALPY:

BTU/LBMOL	-1.2045+05	-1.2042+05	-1.2211+05	-1.2211+05	-1.2265+05
BTU/LB	-6686.0829	-6684.4790	-6777.9843	-6778.1768	-6808.0526
BTU/HR	-1.6192+09	-1.6188+09	-1.4003+07	-1.4004+07	-1.2628+09
ENTROPY:					
BTU/LBMOL-R	-34.9473	-34.9399	-37.5992	-37.5999	-38.5541
BTU/LB-R	-1.9399	-1.9395	-2.0871	-2.0871	-2.1401
DENSITY:					
LBMOL/CUFT	3.3208	3.3247	3.4263	3.4258	3.4484
LB/CUFT	59.8245	59.8946	61.7263	61.7174	62.1236
AVG MW	18.0153	18.0153	18.0153	18.0153	18.0153

SW-3

STREAM ID SW-3
FROM : P-202
TO : ----

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
WATER 1.0296+04
TOTAL FLOW:
LBMOL/HR 1.0296+04
LB/HR 1.8548+05
CUFT/HR 2985.4456
STATE VARIABLES:
TEMP F 90.0250
PRES PSIA 60.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2265+05
BTU/LB -6807.9607
BTU/HR -1.2627+09
ENTROPY:
BTU/LBMOL-R -38.5538
BTU/LB-R -2.1401
DENSITY:
LBMOL/CUFT 3.4486
LB/CUFT 62.1281
AVG MW 18.0153

Section 200: Blower block and streams

BLOCK: B-201 MODEL: COMPR

INLET STREAM: FU-1

OUTLET STREAM: FU-2

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	358.697	358.697	0.00000
MASS(LB/HR)	1787.00	1787.00	0.00000
ENTHALPY(BTU/HR)	-746094.	-150451.	-0.798349

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 14975.0 LB/HR

PRODUCT STREAMS CO2E 14975.0 LB/HR

NET STREAMS CO2E PRODUCTION 0.00000 LB/HR

UTILITIES CO2E PRODUCTION 0.00000 LB/HR

TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

PRESSURE CHANGE PSI 40.0000

ISENTROPIC EFFICIENCY 1.00000

MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP	234.097
BRAKE HORSEPOWER REQUIREMENT HP	234.097
NET WORK REQUIRED HP	234.097
POWER LOSSES HP	0.0
ISENTROPIC HORSEPOWER REQUIREMENT HP	234.097
CALCULATED OUTLET PRES PSIA	54.7000
CALCULATED OUTLET TEMP F	292.893
ISENTROPIC TEMPERATURE F	292.893
EFFICIENCY (POLYTR/ISENTR) USED	1.00000
OUTLET VAPOR FRACTION	1.00000
HEAD DEVELOPED, FT-LBF/LB	259,380.
MECHANICAL EFFICIENCY USED	1.00000
INLET HEAT CAPACITY RATIO	1.37987
INLET VOLUMETRIC FLOW RATE , CUFT/HR	138,773.
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR	53,056.1
INLET COMPRESSIBILITY FACTOR	1.00053
OUTLET COMPRESSIBILITY FACTOR	1.00183
AV. ISENT. VOL. EXPONENT	1.36665
AV. ISENT. TEMP EXPONENT	1.36481
AV. ACTUAL VOL. EXPONENT	1.36665
AV. ACTUAL TEMP EXPONENT	1.36481

FU-1

STREAM ID FU-1

FROM : ----

TO : B-201

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LBMOL/HR

HYDROGEN	300.6131
METHANE	37.3377
ETHANE	0.0
ETHENE	20.7459
PROPANE	0.0
PROPENE	0.0
BUTANE	0.0
WATER	0.0

TOTAL FLOW:

LBMOL/HR	358.6967
LB/HR	1787.0000
CUFT/HR	1.3877+05

STATE VARIABLES:

TEMP F	70.0000
PRES PSIA	14.7000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0

ENTHALPY:

BTU/LBMOL	-2080.0146
BTU/LB	-417.5123
BTU/HR	-7.4609+05

ENTROPY:

BTU/LBMOL-R	-1.7497
BTU/LB-R	-0.3512

DENSITY:

LBMOL/CUFT	2.5848-03
LB/CUFT	1.2877-02

AVG MW 4.9819

FU-2

STREAM ID FU-2

FROM : B-201

TO : ----

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LBMOL/HR

HYDROGEN	300.6131
METHANE	37.3377
ETHANE	0.0
ETHENE	20.7459

PROPANE	0.0
PROPENE	0.0
BUTANE	0.0
WATER	0.0
TOTAL FLOW:	
LBMOL/HR	358.6967
LB/HR	1787.0000
CUFT/HR	5.3056+04
STATE VARIABLES:	
TEMP F	292.8926
PRES PSIA	54.7000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-419.4368
BTU/LB	-84.1917
BTU/HR	-1.5045+05
ENTROPY:	
BTU/LBMOL-R	-1.7497
BTU/LB-R	-0.3512
DENSITY:	
LBMOL/CUFT	6.7607-03
LB/CUFT	3.3681-02
AVG MW	4.9819

```
BLOCK:  C2-SPLIT MODEL: RADFRAC
-------------------------------
CONFIGURATION JUSTIFICATION
  INLETS   - C2-FEED  STAGE  12
  OUTLETS  - ETHYLENE STAGE   1
             ETHANE   STAGE  25
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

              ***  MASS AND ENERGY BALANCE  ***
                         IN           OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          53.4498        53.4498       0.132937E-15
    MASS(LB/HR   )         1500.00        1500.00       0.114201E-08
    ENTHALPY(BTU/HR  )       682408.        904484.      -0.245528

              ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E            180.747      LB/HR
  PRODUCT STREAMS CO2E         180.747      LB/HR
  NET STREAMS CO2E PRODUCTION  0.306777E-05  LB/HR
  UTILITIES CO2E PRODUCTION     0.00000      LB/HR
  TOTAL CO2E PRODUCTION        0.306777E-05  LB/HR



               **********************
               ****  INPUT DATA  ****
               **********************

 ****   INPUT PARAMETERS   ****

  NUMBER OF STAGES                                25
  ALGORITHM OPTION                              STANDARD
  ABSORBER OPTION                               NO
  INITIALIZATION OPTION                         STANDARD
  HYDRAULIC PARAMETER CALCULATIONS              NO
  INSIDE LOOP CONVERGENCE METHOD                BROYDEN
  DESIGN SPECIFICATION METHOD                   NESTED
  MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS        70
  MAXIMUM NO. OF INSIDE LOOP ITERATIONS         10
  MAXIMUM NUMBER OF FLASH ITERATIONS            30
  FLASH TOLERANCE                               0.000100000
  OUTSIDE LOOP CONVERGENCE TOLERANCE            0.000100000
```

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST		1.00000
MASS REFLUX RATIO		10.0000
MASS DISTILLATE RATE	LB/HR	1,410.00

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 290.000

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS	
	ETHYLENE	ETHANE
COMPONENT:		
HYDROGEN	1.0000	0.0000
METHANE	1.0000	.12196E-10
ETHENE	.99649	.35118E-02
ETHANE	.73807E-01	.92619
PROPENE	.51892E-08	1.0000
PROPANE	.51391E-09	1.0000

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	-20.5717
BOTTOM STAGE TEMPERATURE	F	17.2805
TOP STAGE LIQUID FLOW	LBMOL/HR	502.847
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	3.00479
TOP STAGE VAPOR FLOW	LBMOL/HR	50.4450
BOILUP VAPOR FLOW	LBMOL/HR	524.493
MOLAR REFLUX RATIO		9.96823
MOLAR BOILUP RATIO		174.552
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-1,968,990.
REBOILER DUTY	BTU/HR	2,191,070.

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT	0.16117E-04	STAGE= 18
BUBBLE POINT	0.19627E-04	STAGE= 16

COMPONENT MASS BALANCE 0.18410E-04 STAGE= 12 COMP=HYDROGEN
ENERGY BALANCE 0.10868E-04 STAGE= 18

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	-20.572	290.00	16554.	20210.	-.19690+07
2	-19.359	293.00	16513.	20446.	
11	-16.354	294.26	11421.	16869.	
12	-15.563	294.40	9959.4	15793.	
13	-14.288	294.54	7731.8	14157.	
14	-12.667	294.68	4822.2	11934.	
24	15.980	296.08	-36786.	-30548.	
25	17.281	296.22	-38271.	-32600.	.21911+07

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	502.8	50.44			50.4449		
2	505.3	553.3					
11	501.3	552.8					
12	559.5	551.7	53.4497				
13	557.3	556.5					
14	554.3	554.3					
24	527.5	524.8					
25	3.005	524.5		3.0047			

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR LIQUID	FLOW RATE LB/HR VAPOR	FEED RATE LB/HR LIQUID	FEED RATE LB/HR VAPOR	FEED RATE LB/HR MIXED	PRODUCT RATE LB/HR LIQUID	PRODUCT RATE LB/HR VAPOR
1	0.1410E+05	1410.			1410.0000		
2	0.1418E+05	0.1551E+05					
11	0.1416E+05	0.1558E+05					
12	0.1583E+05	0.1557E+05	1499.9994				
13	0.1581E+05	0.1574E+05					
14	0.1578E+05	0.1572E+05					

24	0.1577E+05	0.1565E+05	
25	90.00	0.1568E+05	89.9994

**** MOLE-X-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.52092E-05	0.21799E-02	0.99143	0.63888E-02	0.33805E-16
2	0.64202E-06	0.68702E-03	0.99050	0.88088E-02	0.14279E-15
11	0.50923E-06	0.25772E-03	0.90403	0.95712E-01	0.42671E-10
12	0.51146E-06	0.25792E-03	0.87922	0.12052	0.16660E-09
13	0.17250E-07	0.63516E-04	0.84142	0.15852	0.16885E-09
14	0.58399E-09	0.15597E-04	0.79203	0.20796	0.17190E-09
24	0.16361E-23	0.80908E-11	0.83754E-01	0.91625	0.91450E-08
25	0.59514E-25	0.18292E-11	0.58362E-01	0.94164	0.23602E-07

**** MOLE-X-PROFILE ****

STAGE	PROPANE
1	0.38339E-20
2	0.19454E-19
11	0.31625E-13
12	0.14962E-12
13	0.15119E-12
14	0.15331E-12
24	0.70499E-11
25	0.22385E-10

**** MOLE-Y-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.16229E-03	0.89337E-02	0.98643	0.44697E-02	0.72954E-17
2	0.19531E-04	0.27956E-02	0.99097	0.62138E-02	0.31388E-16
11	0.15270E-04	0.10492E-02	0.92996	0.68978E-01	0.98115E-11
12	0.15301E-04	0.10509E-02	0.91156	0.87370E-01	0.38770E-10
13	0.51422E-06	0.25931E-03	0.88366	0.11608	0.40068E-10
14	0.17344E-07	0.63860E-04	0.84566	0.15427	0.41819E-10
24	0.45442E-22	0.35831E-10	0.11901	0.88099	0.34456E-08
25	0.16451E-23	0.81267E-11	0.83899E-01	0.91610	0.90621E-08

**** MOLE-Y-PROFILE ****

STAGE	PROPANE
1	0.68522E-21
2	0.35468E-20
11	0.60079E-14
12	0.28733E-13
13	0.29561E-13
14	0.30666E-13
24	0.21515E-11
25	0.69621E-11

**** K-VALUES ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	31.155	4.0983	0.99497	0.69961	0.21581
2	30.421	4.0692	1.0005	0.70541	0.21982
11	29.994	4.0719	1.0287	0.72073	0.22991
12	29.927	4.0759	1.0368	0.72501	0.23266
13	29.827	4.0842	1.0502	0.73237	0.23724
14	29.722	4.0965	1.0677	0.74192	0.24318
24	27.785	4.4294	1.4210	0.96152	0.37673
25	27.650	4.4433	1.4376	0.97288	0.38392

**** K-VALUES ****

STAGE	PROPANE
1	0.17873
2	0.18232
11	0.18996
12	0.19202
13	0.19548
14	0.19996
24	0.30515
25	0.31099

**** MASS-X-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.37450E-06	0.12472E-02	0.99190	0.68512E-02	0.50732E-16
2	0.46118E-07	0.39275E-03	0.99017	0.94386E-02	0.21411E-15
11	0.36346E-07	0.14639E-03	0.89795	0.10190	0.63576E-10
12	0.36441E-07	0.14624E-03	0.87177	0.12808	0.24779E-09
13	0.12256E-08	0.35914E-04	0.83196	0.16800	0.25043E-09
14	0.41346E-10	0.87879E-05	0.78037	0.21962	0.25406E-09
24	0.11030E-24	0.43410E-11	0.78580E-01	0.92142	0.12870E-07
25	0.40055E-26	0.97975E-12	0.54663E-01	0.94534	0.33159E-07

**** MASS-X-PROFILE ****

STAGE	PROPANE
1	0.60292E-20
2	0.30569E-19
11	0.49375E-13
12	0.23318E-12
13	0.23498E-12
14	0.23744E-12
24	0.10397E-10
25	0.32955E-10

**** MASS-Y-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.11705E-04	0.51276E-02	0.99005	0.48084E-02	0.10983E-16
2	0.14045E-05	0.15999E-02	0.99173	0.66655E-02	0.47119E-16
11	0.10924E-05	0.59733E-03	0.92580	0.73603E-01	0.14651E-10
12	0.10931E-05	0.59752E-03	0.90629	0.93107E-01	0.57818E-10
13	0.36649E-07	0.14708E-03	0.87644	0.12341	0.59611E-10
14	0.12326E-08	0.36119E-04	0.83641	0.16355	0.62042E-10
24	0.30709E-23	0.19271E-10	0.11193	0.88807	0.48607E-08
25	0.11091E-24	0.43603E-11	0.78717E-01	0.92128	0.12754E-07

**** MASS-Y-PROFILE ****

STAGE	PROPANE
1	0.10810E-20
2	0.55794E-20
11	0.94014E-14
12	0.44904E-13
13	0.46086E-13
14	0.47675E-13
24	0.31806E-11
25	0.10267E-10

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

TEMPERATURE

STAGE	F LIQUID FROM	VAPOR TO
1	-20.572	-19.359
2	-19.359	-19.135
11	-16.354	-15.563
12	-15.563	-14.288
13	-14.288	-12.667
14	-12.667	-10.589
24	15.980	17.281
25	17.281	17.281

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	14100.	15510.	515.12	6453.2	28.040	28.032
2	14180.	15590.	519.40	6479.5	28.063	28.053
11	14158.	15568.	520.00	6453.0	28.244	28.217
12	15830.	15740.	581.78	6523.4	28.294	28.285
13	15812.	15722.	581.74	6518.4	28.373	28.364
14	15784.	15694.	581.57	6511.3	28.473	28.465
24	15773.	15683.	604.19	6483.1	29.901	29.901
25	89.999	0.0000	3.4553	0.0000	29.952	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	27.372	2.4035	0.64998E-01	0.93924E-02	7.6060
2	27.302	2.4061	0.64853E-01	0.93953E-02	7.5444
11	27.228	2.4126	0.65274E-01	0.94164E-02	7.4496
12	27.210	2.4129	0.65393E-01	0.94217E-02	7.4039
13	27.180	2.4119	0.65582E-01	0.94273E-02	7.3713
14	27.140	2.4102	0.65798E-01	0.94336E-02	7.2227
24	26.105	2.4190	0.64439E-01	0.94710E-02	6.0712
25	26.047		0.64137E-01		6.0187

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.26938	2002.1	10004.
2	-.61637E-01	0.27002	2014.4	10051.
11	-.19261E-01	0.27071	2012.1	10023.
12	-.15918	0.29949	2034.9	10133.
13	-.32547E-01	0.29960	2034.1	10123.

14	-.14864	0.29971	2032.8	10109.
24	-.70344E-01	0.30615	2071.8	10083.
25	-.52559E-01		0.0000	0.0000

****
***** TRAY SIZING CALCULATIONS *****
****

****
*** SECTION 1 ***
****

STARTING STAGE NUMBER		2
ENDING STAGE NUMBER		24
FLOODING CALCULATION METHOD		GLITSCH6

DESIGN PARAMETERS

PEAK CAPACITY FACTOR		1.00000
SYSTEM FOAMING FACTOR		1.00000
FLOODING FACTOR		0.80000
MINIMUM COLUMN DIAMETER	FT	1.00000
MINIMUM DC AREA/COLUMN AREA		0.100000
HOLE AREA/ACTIVE AREA		0.100000
DOWNCOMER DESIGN BASIS		EQUAL FLOW PATH LENGTH

TRAY SPECIFICATIONS

TRAY TYPE		SIEVE
NUMBER OF PASSES		1
TRAY SPACING	FT	1.50000

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER		24
COLUMN DIAMETER	FT	2.06458
DC AREA/COLUMN AREA		0.18162
DOWNCOMER VELOCITY	FT/SEC	0.27603
FLOW PATH LENGTH PER PANEL	FT	1.08472
SIDE DOWNCOMER WIDTH	FT	0.48993
SIDE WEIR LENGTH	FT	1.75667

CENTER DOWNCOMER WIDTH	FT	0.0
CENTER WEIR LENGTH	FT	MISSING
OFF-CENTER DOWNCOMER WIDTH	FT	0.0
OFF-CENTER SHORT WEIR LENGTH	FT	MISSING
OFF-CENTER LONG WEIR LENGTH	FT	MISSING
TRAY CENTER TO OCDC CENTER	FT	0.0

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	FT	SQFT	SQFT	SQFT
2	2.0646	3.3478	2.1317	0.60802
3	2.0646	3.3478	2.1317	0.60802
4	2.0646	3.3478	2.1317	0.60802
5	2.0646	3.3478	2.1317	0.60802
6	2.0646	3.3478	2.1317	0.60802
7	2.0646	3.3478	2.1317	0.60802
8	2.0646	3.3478	2.1317	0.60802
9	2.0646	3.3478	2.1317	0.60802
10	2.0646	3.3478	2.1317	0.60802
11	2.0646	3.3478	2.1317	0.60802
12	2.0646	3.3478	2.1317	0.60802
13	2.0646	3.3478	2.1317	0.60802
14	2.0646	3.3478	2.1317	0.60802
15	2.0646	3.3478	2.1317	0.60802
16	2.0646	3.3478	2.1317	0.60802
17	2.0646	3.3478	2.1317	0.60802
18	2.0646	3.3478	2.1317	0.60802
19	2.0646	3.3478	2.1317	0.60802
20	2.0646	3.3478	2.1317	0.60802
21	2.0646	3.3478	2.1317	0.60802
22	2.0646	3.3478	2.1317	0.60802
23	2.0646	3.3478	2.1317	0.60802
24	2.0646	3.3478	2.1317	0.60802

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP	DC BACKUP	DC BACKUP/ (TSPC+WHT)
		PSI	FT	
2	76.71	0.7567E-01	0.7804	48.03
3	76.74	0.7569E-01	0.7809	48.06
4	76.74	0.7569E-01	0.7811	48.07
5	76.74	0.7569E-01	0.7812	48.07

6	76.74	0.7568E-01	0.7813	48.08
7	76.73	0.7566E-01	0.7814	48.08
8	76.71	0.7564E-01	0.7814	48.09
9	76.70	0.7561E-01	0.7815	48.09
10	76.68	0.7557E-01	0.7815	48.09
11	76.65	0.7551E-01	0.7815	48.09
12	78.38	0.7674E-01	0.8249	50.77
13	78.35	0.7665E-01	0.8253	50.79
14	78.30	0.7649E-01	0.8254	50.79
15	78.25	0.7631E-01	0.8260	50.83
16	78.22	0.7611E-01	0.8273	50.91
17	78.24	0.7590E-01	0.8297	51.06
18	78.33	0.7572E-01	0.8335	51.30
19	78.52	0.7559E-01	0.8389	51.62
20	78.79	0.7552E-01	0.8454	52.03
21	79.12	0.7550E-01	0.8524	52.46
22	79.44	0.7553E-01	0.8593	52.88
23	79.75	0.7558E-01	0.8653	53.25
24	80.00	0.7563E-01	0.8704	53.56

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.2752	0.5041	0.2460	46.88
3	0.2755	0.5039	0.2460	46.90
4	0.2756	0.5039	0.2460	46.91
5	0.2756	0.5038	0.2461	46.92
6	0.2755	0.5037	0.2461	46.92
7	0.2755	0.5036	0.2462	46.93
8	0.2754	0.5035	0.2462	46.93
9	0.2753	0.5033	0.2463	46.94
10	0.2751	0.5032	0.2464	46.95
11	0.2749	0.5030	0.2465	46.96
12	0.3364	0.5028	0.2446	47.66
13	0.3354	0.5024	0.2448	47.68
14	0.3338	0.5019	0.2450	47.88
15	0.3322	0.5012	0.2453	47.97
16	0.3313	0.5002	0.2456	48.11
17	0.3315	0.4990	0.2460	48.30
18	0.3336	0.4974	0.2462	48.57
19	0.3391	0.4957	0.2463	48.91
20	0.3519	0.4938	0.2463	49.30
21	0.3536	0.4920	0.2461	49.71
22	0.3553	0.4904	0.2459	50.10
23	0.3569	0.4890	0.2457	50.44
24	0.3582	0.4880	0.2454	50.72

BLOCK: DEETH MODEL: RADFRAC

CONFIGURATION NOTES
INLETS - C2H4-REC STAGE 20
OUTLETS - H2-CH4-2 STAGE 1
DE-BOT STAGE 32
C2-OUT STAGE 6
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	73.3744	73.3744	0.387352E-15
MASS(LB/HR)	2097.60	2097.60	0.386560E-07
ENTHALPY(BTU/HR)	258065.	403615.	-0.360615

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 2281.18 LB/HR
PRODUCT STREAMS CO2E 2281.14 LB/HR
NET STREAMS CO2E PRODUCTION -0.421563E-01 LB/HR
UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2E PRODUCTION -0.421563E-01 LB/HR

****
**** INPUT DATA ****
****

**** INPUT PARAMETERS ****

NUMBER OF STAGES	32
ALGORITHM OPTION	STANDARD
ABSORBER OPTION	NO
INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	BROYDEN
DESIGN SPECIFICATION METHOD	NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	70
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	0.000100000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST 1.00000
MASS REFLUX RATIO 25.0000
MASS DISTILLATE RATE LB/HR 120.000

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 200.000

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS		
	H2-CH4-2	DE-BOT	C2-OUT
COMPONENT:			
HYDROGEN	.99372	0.0000	.62819E-02
METHANE	.92076	.67575E-11	.79235E-01
ETHENE	.23133E-01	.20315E-02	.97484
ETHANE	.72976E-03	.49190	.50737
PROPENE	.11939E-14	1.0000	.79918E-08
PROPANE	0.0000	1.0000	.30339E-09
BUTANE	0.0000	1.0000	.46527E-13

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE F -129.792
BOTTOM STAGE TEMPERATURE F 57.4754
TOP STAGE LIQUID FLOW LBMOL/HR 120.520
BOTTOM STAGE LIQUID FLOW LBMOL/HR 12.2031
TOP STAGE VAPOR FLOW LBMOL/HR 7.72145
BOILUP VAPOR FLOW LBMOL/HR 129.144
MOLAR REFLUX RATIO 15.6084
MOLAR BOILUP RATIO 10.5829
CONDENSER DUTY (W/O SUBCOOL) BTU/HR -603,649.
REBOILER DUTY BTU/HR 749,187.

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT 0.34770E-04 STAGE= 1
BUBBLE POINT 0.11244E-03 STAGE= 1

COMPONENT MASS BALANCE   0.33906E-04 STAGE= 1 COMP=HYDROGEN
ENERGY BALANCE   0.17310E-03 STAGE= 1

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

```
                            ENTHALPY
STAGE TEMPERATURE   PRESSURE          BTU/LBMOL         HEAT DUTY
     F          PSIA        LIQUID      VAPOR       BTU/HR

  1  -129.79      200.00      1369.1     -20170.    -.60365+06
  2  -63.032      203.00      12523.      4781.8
  5  -44.805      203.42      13805.      16820.
  6  -44.162      203.56      12709.      16185.
  7  -43.356      203.70      11095.      15153.
 18  -38.984      205.24      3806.7      10232.
 19  -37.940      205.38      3639.1      10142.
 20  -34.323      205.52      3485.3      10268.
 21  -29.695      205.66      362.63      9156.3
 22  -26.598      205.80     -3897.0      5792.0
 23  -23.249      205.94     -8952.0      1242.1
 31   33.509      207.06     -18233.    -22321.
 32   57.475      207.20     -9828.5    -13226.      .74919+06
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STAGE    FLOW RATE              FEED RATE             PRODUCT RATE
        LBMOL/HR             LBMOL/HR             LBMOL/HR
    LIQUID    VAPOR     LIQUID    VAPOR    MIXED     LIQUID    VAPOR
  1  120.5    7.721                             7.7214
  2  131.5    128.2
  5  135.6    143.4
  6  135.4    143.4                      53.4497
  7  81.69    143.1
 18  80.01    141.6
 19  78.73    141.2          1.4150
 20  173.0    138.5     71.9593
 21  173.1    160.8
 22  172.1    160.9
 23  170.8    159.9
 31  141.3    137.6
 32  12.20    129.1                      12.2031
```

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR LIQUID	VAPOR	FEED RATE LB/HR LIQUID	VAPOR	MIXED	PRODUCT RATE LB/HR LIQUID	VAPOR
1	3000.	120.0			120.0022		
2	3597.	3120.					
5	3801.	3916.					
6	3799.	3921.		1499.9994			
7	2297.	3919.					
18	2277.	3904.					
19	2256.	3897.	12.0557				
20	5063.	3864.	2085.5432				
21	5104.	4586.					
22	5105.	4626.					
23	5101.	4628.					
31	5156.	4582.					
32	477.6	4679.		477.5973			

**** MOLE-X-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.18494E-02	0.26007	0.73278	0.52968E-02	0.94921E-13
2	0.17643E-03	0.59178E-01	0.93003	0.10614E-01	0.87003E-12
5	0.15267E-03	0.86938E-02	0.95281	0.38340E-01	0.21962E-09
6	0.15317E-03	0.84315E-02	0.93426	0.57155E-01	0.13268E-08
7	0.15391E-03	0.83886E-02	0.90692	0.84541E-01	0.78931E-08
18	0.15802E-03	0.83840E-02	0.77876	0.20620	0.63980E-02
19	0.15743E-03	0.83051E-02	0.76561	0.20478	0.20727E-01
20	0.46952E-04	0.77543E-02	0.73220	0.19475	0.63477E-01
21	0.86232E-06	0.14602E-02	0.67844	0.25383	0.64483E-01
22	0.15992E-07	0.27228E-03	0.60499	0.32687	0.66053E-01
23	0.29923E-09	0.50226E-04	0.51771	0.41237	0.68009E-01
31	0.55309E-23	0.27057E-10	0.21419E-01	0.44446	0.52151
32	0.10876E-24	0.31495E-11	0.85277E-02	0.24270	0.72719

**** MOLE-X-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.28253E-16	0.76968E-22
2	0.33175E-15	0.14779E-20
5	0.16584E-12	0.29287E-17
6	0.12584E-11	0.36274E-16
7	0.94174E-11	0.45713E-15
18	0.96714E-04	0.40130E-05
19	0.39515E-03	0.32460E-04
20	0.15129E-02	0.25884E-03
21	0.15298E-02	0.25855E-03
22	0.15587E-02	0.25982E-03

23	0.15945E-02	0.26162E-03
31	0.11718E-01	0.89081E-03
32	0.18167E-01	0.34148E-02

**** MOLE-Y-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.16772	0.67824	0.15347	0.56905E-03	0.13721E-14
2	0.11837E-01	0.28525	0.69790	0.50121E-02	0.89289E-13
5	0.91759E-02	0.46111E-01	0.92051	0.24204E-01	0.33975E-10
6	0.91783E-02	0.44756E-01	0.90976	0.36306E-01	0.20780E-09
7	0.91949E-02	0.44572E-01	0.89213	0.54101E-01	0.12552E-08
18	0.92912E-02	0.44932E-01	0.80706	0.13760	0.11022E-02
19	0.93213E-02	0.45040E-01	0.80343	0.13852	0.36257E-02
20	0.28192E-02	0.43632E-01	0.80311	0.13843	0.11771E-01
21	0.50517E-04	0.83429E-02	0.78713	0.19111	0.13094E-01
22	0.92773E-06	0.15710E-02	0.72925	0.25468	0.14218E-01
23	0.17213E-07	0.29307E-03	0.65052	0.33329	0.15585E-01
31	0.31760E-21	0.22472E-09	0.47197E-01	0.67667	0.27080
32	0.60433E-23	0.29317E-10	0.22638E-01	0.46352	0.50208

**** MOLE-Y-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.28157E-18	0.33159E-24
2	0.26568E-16	0.72353E-22
5	0.20447E-13	0.22599E-18
6	0.15691E-12	0.27709E-17
7	0.11905E-11	0.34317E-16
18	0.13176E-04	0.28174E-06
19	0.54808E-04	0.22741E-05
20	0.22442E-03	0.18439E-04
21	0.24861E-03	0.19261E-04
22	0.26790E-03	0.19153E-04
23	0.29093E-03	0.18983E-04
31	0.52196E-02	0.11705E-03
32	0.11108E-01	0.65230E-03

**** K-VALUES ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	90.721	2.6082	0.20941	0.10743	0.14451E-01
2	67.086	4.8201	0.75041	0.47223	0.10263
5	60.103	5.3039	0.96610	0.63128	0.15469
6	59.922	5.3082	0.97377	0.63522	0.15661
7	59.742	5.3135	0.98370	0.63995	0.15903
18	58.797	5.3593	1.0363	0.66730	0.17227
19	59.210	5.4232	1.0494	0.67646	0.17493
20	60.045	5.6269	1.0968	0.71079	0.18543

21	58.582	5.7135	1.1602	0.75292	0.20306
22	58.012	5.7697	1.2054	0.77914	0.21526
23	57.523	5.8349	1.2565	0.80823	0.22916
31	57.427	8.3057	2.2035	1.5225	0.51926
32	55.570	9.3084	2.6546	1.9098	0.69044

**** K-VALUES ****

STAGE	PROPANE	BUTANE
1	0.99639E-02	0.43083E-02
2	0.80090E-01	0.48958E-01
5	0.12329	0.77163E-01
6	0.12469	0.76389E-01
7	0.12641	0.75071E-01
18	0.13623	0.70207E-01
19	0.13870	0.70060E-01
20	0.14834	0.71239E-01
21	0.16251	0.74498E-01
22	0.17187	0.73717E-01
23	0.18246	0.72560E-01
31	0.44543	0.13139
32	0.61146	0.19102

**** MASS-X-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.14977E-03	0.16761	0.82584	0.63984E-02	0.16046E-12
2	0.13000E-04	0.34700E-01	0.95362	0.11665E-01	0.13382E-11
5	0.10983E-04	0.49771E-02	0.95387	0.41141E-01	0.32980E-09
6	0.11003E-04	0.48199E-02	0.93393	0.61240E-01	0.19895E-08
7	0.11034E-04	0.47859E-02	0.90480	0.90404E-01	0.11812E-07
18	0.11195E-04	0.47267E-02	0.76775	0.21789	0.94614E-02
19	0.11073E-04	0.46488E-02	0.74939	0.21484	0.30432E-01
20	0.32332E-05	0.42494E-02	0.70166	0.20004	0.91246E-01
21	0.58957E-07	0.79451E-03	0.64551	0.25887	0.92030E-01
22	0.10866E-08	0.14723E-03	0.57206	0.33128	0.93686E-01
23	0.20193E-10	0.26974E-04	0.48620	0.41510	0.95804E-01
31	0.30564E-24	0.11899E-10	0.16472E-01	0.36636	0.60158
32	0.56018E-26	0.12910E-11	0.61127E-02	0.18647	0.78187

**** MASS-X-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.50049E-16	0.17972E-21
2	0.53469E-15	0.31398E-20
5	0.26097E-12	0.60745E-17
6	0.19773E-11	0.75128E-16
7	0.14768E-10	0.94489E-15
18	0.14987E-03	0.81968E-05

19	0.60796E-03	0.65829E-04
20	0.22789E-02	0.51391E-03
21	0.22879E-02	0.50968E-03
22	0.23167E-02	0.50901E-03
23	0.23538E-02	0.50905E-03
31	0.14165E-01	0.14193E-02
32	0.20469E-01	0.50714E-02

**** MASS-Y-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.21756E-01	0.70012	0.27703	0.11010E-02	0.37151E-14
2	0.98080E-03	0.18809	0.80473	0.61946E-02	0.15443E-12
5	0.67732E-03	0.27087E-01	0.94559	0.26649E-01	0.52350E-10
6	0.67649E-03	0.26252E-01	0.93316	0.39915E-01	0.31971E-09
7	0.67678E-03	0.26109E-01	0.91382	0.59398E-01	0.19286E-08
18	0.67948E-03	0.26150E-01	0.82137	0.15010	0.16826E-02
19	0.68080E-03	0.26179E-01	0.81661	0.15091	0.55278E-02
20	0.20367E-03	0.25085E-01	0.80740	0.14917	0.17750E-01
21	0.35700E-05	0.46920E-02	0.77411	0.20146	0.19316E-01
22	0.65044E-07	0.87654E-03	0.71152	0.26634	0.20809E-01
23	0.11987E-08	0.16243E-03	0.63047	0.34623	0.22657E-01
31	0.19224E-22	0.10825E-09	0.39757E-01	0.61096	0.34217
32	0.33627E-24	0.12982E-10	0.17530E-01	0.38472	0.58318

**** MASS-Y-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.79891E-18	0.12401E-23
2	0.48154E-16	0.17285E-21
5	0.33015E-13	0.48097E-18
6	0.25298E-12	0.58886E-17
7	0.19168E-11	0.72828E-16
18	0.21077E-04	0.59406E-06
19	0.87562E-04	0.47890E-05
20	0.35464E-03	0.38408E-04
21	0.38431E-03	0.39246E-04
22	0.41087E-03	0.38718E-04
23	0.44321E-03	0.38118E-04
31	0.69111E-02	0.20428E-03
32	0.13521E-01	0.10465E-02

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)

WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	-129.79	-63.032
2	-63.032	-48.675
5	-44.805	-44.162
6	-44.162	-43.356
7	-43.356	-42.655
18	-38.984	-37.940
19	-37.940	-35.319
20	-34.323	-29.695
21	-29.695	-26.598
22	-26.598	-23.249
23	-23.249	-19.471
31	33.509	57.475
32	57.475	57.475

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	3000.0	3120.0	97.286	2208.6	24.893	24.330
2	3597.1	3717.1	121.42	2425.8	27.360	26.704
5	3801.1	3921.1	130.48	2504.2	28.023	27.350
6	3799.5	3919.5	130.50	2502.9	28.064	27.388
7	2297.0	3916.9	78.956	2501.0	28.119	27.419
18	2276.6	3896.6	78.451	2483.1	28.456	27.601

19	2256.4	3876.4	77.431	2483.3	28.661	27.709
20	5063.4	4585.8	171.84	2861.1	29.274	28.526
21	5103.8	4626.2	174.10	2879.1	29.485	28.753
22	5105.1	4627.5	174.73	2879.7	29.669	28.946
23	5101.5	4623.8	175.27	2877.6	29.872	29.159
31	5156.3	4678.7	169.37	2747.3	36.480	36.229
32	477.60	0.0000	15.496	0.0000	39.137	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	30.837	1.4127	0.86819E-01	0.83766E-02	13.439
2	29.626	1.5323	0.73398E-01	0.85167E-02	9.8717
5	29.132	1.5658	0.74237E-01	0.85563E-02	8.9424
6	29.114	1.5660	0.74374E-01	0.85610E-02	8.9190
7	29.092	1.5662	0.74569E-01	0.85651E-02	8.8919
18	29.020	1.5693	0.75457E-01	0.86095E-02	8.7241
19	29.141	1.5610	0.75895E-01	0.86442E-02	8.7409
20	29.466	1.6028	0.77036E-01	0.86899E-02	8.7934
21	29.315	1.6068	0.77462E-01	0.87026E-02	8.6017
22	29.217	1.6069	0.77873E-01	0.87130E-02	8.4923
23	29.106	1.6068	0.78232E-01	0.87224E-02	8.3794
31	30.444	1.7030	0.79582E-01	0.93477E-02	7.7081
32	30.821		0.77233E-01		7.3778

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.20580	483.93	2625.1
2	-3.5673	0.22008	566.54	3002.8
5	-.39396E-01	0.22474	596.82	3133.5
6	-.23420E-01	0.22482	596.74	3132.1
7	-.27114E-01	0.13606	596.57	3129.9
18	0.55426E-02	0.13586	593.70	3110.6
19	0.16845E-01	0.13472	590.78	3102.6
20	-2.5151	0.25752	686.21	3622.2
21	-.19177	0.25829	693.33	3649.6
22	-.10940	0.25873	694.73	3650.5
23	-.11288	0.25923	695.60	3647.7
31	-.47288E-01	0.26066	668.74	3585.2
32	-.33030		0.0000	0.0000

```
          ***********************************
          ***** TRAY SIZING CALCULATIONS *****
          ***********************************


*******************
*** SECTION   1 ***
*******************

STARTING STAGE NUMBER                          2
ENDING STAGE NUMBER                           31
FLOODING CALCULATION METHOD                        GLITSCH6

DESIGN PARAMETERS
-----------------
PEAK CAPACITY FACTOR                        1.00000
SYSTEM FOAMING FACTOR                         1.00000
FLOODING FACTOR                          0.80000
MINIMUM COLUMN DIAMETER        FT                  1.00000
MINIMUM DC AREA/COLUMN AREA                        0.100000
HOLE AREA/ACTIVE AREA                        0.100000
DOWNCOMER DESIGN BASIS                    EQUAL FLOW PATH LENGTH

TRAY SPECIFICATIONS
-------------------
TRAY TYPE                              SIEVE
NUMBER OF PASSES                            1
TRAY SPACING               FT                  1.50000


     ***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER                           27
COLUMN DIAMETER              FT                 1.12949
DC AREA/COLUMN AREA                             0.16808
DOWNCOMER VELOCITY            FT/SEC                0.29475
FLOW PATH LENGTH PER PANEL      FT                  0.62194
SIDE DOWNCOMER WIDTH           FT                 0.25378
SIDE WEIR LENGTH              FT                0.94284
CENTER DOWNCOMER WIDTH         FT                  0.0
CENTER WEIR LENGTH            FT                MISSING
OFF-CENTER DOWNCOMER WIDTH      FT                  0.0
OFF-CENTER SHORT WEIR LENGTH    FT                  MISSING
OFF-CENTER LONG WEIR LENGTH    FT                  MISSING
TRAY CENTER TO OCDC CENTER      FT                  0.0
```

**** SIZING PROFILES ****

STAGE	DIAMETER FT	TOTAL AREA SQFT	ACTIVE AREA SQFT	SIDE DC AREA SQFT
2	1.1295	1.0020	0.66515	0.16841
3	1.1295	1.0020	0.66515	0.16841
4	1.1295	1.0020	0.66515	0.16841
5	1.1295	1.0020	0.66515	0.16841
6	1.1295	1.0020	0.66515	0.16841
7	1.1295	1.0020	0.66515	0.16841
8	1.1295	1.0020	0.66515	0.16841
9	1.1295	1.0020	0.66515	0.16841
10	1.1295	1.0020	0.66515	0.16841
11	1.1295	1.0020	0.66515	0.16841
12	1.1295	1.0020	0.66515	0.16841
13	1.1295	1.0020	0.66515	0.16841
14	1.1295	1.0020	0.66515	0.16841
15	1.1295	1.0020	0.66515	0.16841
16	1.1295	1.0020	0.66515	0.16841
17	1.1295	1.0020	0.66515	0.16841
18	1.1295	1.0020	0.66515	0.16841
19	1.1295	1.0020	0.66515	0.16841
20	1.1295	1.0020	0.66515	0.16841
21	1.1295	1.0020	0.66515	0.16841
22	1.1295	1.0020	0.66515	0.16841
23	1.1295	1.0020	0.66515	0.16841
24	1.1295	1.0020	0.66515	0.16841
25	1.1295	1.0020	0.66515	0.16841
26	1.1295	1.0020	0.66515	0.16841
27	1.1295	1.0020	0.66515	0.16841
28	1.1295	1.0020	0.66515	0.16841
29	1.1295	1.0020	0.66515	0.16841
30	1.1295	1.0020	0.66515	0.16841
31	1.1295	1.0020	0.66515	0.16841

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
2	63.72	0.6280E-01	0.5562	34.23
3	66.58	0.6483E-01	0.5823	35.83
4	67.17	0.6523E-01	0.5879	36.18
5	67.26	0.6528E-01	0.5890	36.24

6	67.26	0.6524E-01	0.5891	36.25
7	65.82	0.6369E-01	0.5491	33.79
8	65.80	0.6364E-01	0.5491	33.79
9	65.79	0.6359E-01	0.5492	33.79
10	65.77	0.6355E-01	0.5492	33.80
11	65.76	0.6352E-01	0.5492	33.80
12	65.75	0.6349E-01	0.5493	33.80
13	65.73	0.6347E-01	0.5493	33.80
14	65.72	0.6344E-01	0.5493	33.80
15	65.71	0.6343E-01	0.5492	33.80
16	65.69	0.6340E-01	0.5491	33.79
17	65.64	0.6337E-01	0.5486	33.76
18	65.51	0.6328E-01	0.5471	33.67
19	65.15	0.6309E-01	0.5429	33.41
20	78.02	0.7683E-01	0.6921	42.59
21	78.85	0.7741E-01	0.7024	43.22
22	79.02	0.7736E-01	0.7055	43.41
23	79.13	0.7722E-01	0.7082	43.58
24	79.30	0.7711E-01	0.7118	43.80
25	79.55	0.7706E-01	0.7164	44.09
26	79.83	0.7706E-01	0.7213	44.39
27	80.00	0.7706E-01	0.7243	44.57
28	79.81	0.7692E-01	0.7216	44.40
29	78.85	0.7652E-01	0.7069	43.50
30	77.12	0.7623E-01	0.6795	41.81
31	76.31	0.7744E-01	0.6606	40.65

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.1826	0.5426	0.2539	39.67
3	0.1930	0.5382	0.2475	42.19
4	0.1952	0.5371	0.2463	42.71
5	0.1956	0.5368	0.2462	42.81
6	0.1955	0.5366	0.2463	42.83
7	0.1090	0.5364	0.2464	42.63
8	0.1090	0.5361	0.2465	42.67
9	0.1089	0.5359	0.2466	42.69
10	0.1088	0.5357	0.2467	42.70
11	0.1088	0.5356	0.2468	42.71
12	0.1088	0.5354	0.2469	42.72
13	0.1088	0.5353	0.2469	42.72
14	0.1087	0.5352	0.2470	42.73
15	0.1087	0.5351	0.2471	42.73
16	0.1087	0.5351	0.2472	42.72
17	0.1085	0.5351	0.2473	42.69

18	0.1080	0.5355	0.2475	42.61
19	0.1066	0.5370	0.2479	42.39
20	0.2515	0.5401	0.2223	49.82
21	0.2546	0.5384	0.2212	50.59
22	0.2552	0.5373	0.2211	50.83
23	0.2556	0.5361	0.2212	51.04
24	0.2563	0.5346	0.2213	51.33
25	0.2573	0.5330	0.2213	51.67
26	0.2584	0.5314	0.2211	52.03
27	0.2591	0.5305	0.2211	52.31
28	0.2584	0.5309	0.2213	52.34
29	0.2549	0.5343	0.2223	51.85
30	0.2492	0.5416	0.2239	50.90
31	0.2479	0.5492	0.2239	50.71

BLOCK: DEMETH MODEL: RADFRAC

INLETS - SEP-FEED STAGE 4
OUTLETS - H2-CH4-1 STAGE 1
C2H4-REC STAGE 1
DM-BOT STAGE 12
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	455.421	455.421	0.00000
MASS(LB/HR)	5164.04	5164.04	0.399150E-06
ENTHALPY(BTU/HR)	162107.	-0.123700E+07	1.13105

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 15164.8 LB/HR
PRODUCT STREAMS CO2E 15164.8 LB/HR
NET STREAMS CO2E PRODUCTION 0.199291E-02 LB/HR
UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2E PRODUCTION 0.199291E-02 LB/HR

****
**** INPUT DATA ****
****

**** INPUT PARAMETERS ****

NUMBER OF STAGES 12

ALGORITHM OPTION	STANDARD
ABSORBER OPTION	NO
INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	BROYDEN
DESIGN SPECIFICATION METHOD	NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	70
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	0.000100000

**** COL-SPECS ****

MASS VAPOR DIST / TOTAL DIST		0.44800
MASS REFLUX RATIO		5.00000
MASS DISTILLATE RATE	LB/HR	3,800.00

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 550.000

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

OUTLET STREAMS

COMPONENT:	H2-CH4-1	C2H4-REC	DM-BOT
HYDROGEN	.99567	.43312E-02	.39198E-09
METHANE	.84957	.15043	.16161E-05
ETHENE	.27236	.72617	.14681E-02
ETHANE	.16177	.82800	.10235E-01
PROPENE	.66451E-02	.29018	.70318
PROPANE	.31042E-02	.18771	.80918
BUTANE	.37777E-04	.58465E-02	.99412

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	-131.217
BOTTOM STAGE TEMPERATURE	F	205.243

TOP STAGE LIQUID FLOW LBMOL/HR 664.623
BOTTOM STAGE LIQUID FLOW LBMOL/HR 29.7236
TOP STAGE VAPOR FLOW LBMOL/HR 352.323
BOILUP VAPOR FLOW LBMOL/HR 1,185.29
MOLAR REFLUX RATIO 1.56126
MOLAR BOILUP RATIO 39.8771
CONDENSER DUTY (W/O SUBCOOL) BTU/HR -5,002,050.
REBOILER DUTY BTU/HR 3,602,910.

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT 0.13723E-03 STAGE= 11
BUBBLE POINT 0.13838E-03 STAGE= 11
COMPONENT MASS BALANCE 0.77778E-06 STAGE= 3 COMP=BUTANE
ENERGY BALANCE 0.67885E-04 STAGE= 7

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	-131.22	550.00	3517.1	-3337.9	-.50021+07
2	19.170	553.00	4442.4	5889.6	
3	63.974	553.14	1867.5	6179.8	
4	131.01	553.28	2558.4	7481.3	
8	177.91	553.84	-10.598	4305.6	
9	183.46	553.98	-1520.6	3210.9	
10	189.39	554.12	-3712.9	1659.8	
11	196.50	554.26	-6757.1	-551.07	
12	205.24	554.40	-10733.	-3617.2	.36029+07

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	738.0	352.3				73.3743	352.3234
2	836.8	1090.					
3	738.2	1262.	455.4214				
4	1015.	708.5					
8	1247.	1196.					
9	1249.	1217.					

```
 10  1235.      1219.
 11  1215.      1205.
 12  29.72      1185.                         29.7236

  ****  MASS FLOW PROFILES  ****

STAGE     FLOW RATE               FEED RATE            PRODUCT RATE
         LB/HR                 LB/HR                LB/HR
    LIQUID     VAPOR       LIQUID    VAPOR   MIXED     LIQUID    VAPOR
  1 0.2110E+05  1702.                          2097.5990 1702.3991
  2 0.2725E+05 0.2280E+05
  3 0.2687E+05 0.3105E+05           5164.0430
  4 0.3945E+05 0.2551E+05
  8 0.5299E+05 0.5002E+05
  9 0.5384E+05 0.5163E+05
 10 0.5415E+05 0.5247E+05
 11 0.5437E+05 0.5279E+05
 12  1364.     0.5301E+05                       1364.0427

                ****   MOLE-X-PROFILE    ****
  STAGE     HYDROGEN      METHANE       ETHENE       ETHANE       PROPENE
    1    0.17762E-01   0.77517E-01   0.69813      0.82060E-01   0.12094
    2    0.14586E-01   0.24924E-01   0.52519      0.83510E-01   0.33813
    3    0.14159E-01   0.12233E-01   0.31025      0.62028E-01   0.56654
    4    0.18450E-02   0.41093E-02   0.19965      0.47406E-01   0.70580
    8    0.19803E-05   0.83137E-04   0.29240E-01   0.12011E-01   0.86847
    9    0.40799E-06   0.32928E-04   0.17737E-01   0.83080E-02   0.85768
   10    0.85678E-07   0.13082E-04   0.10575E-01   0.56728E-02   0.83048
   11    0.18282E-07   0.51938E-05   0.61585E-02   0.38082E-02   0.78585
   12    0.39682E-08   0.20558E-05   0.34842E-02   0.25040E-02   0.72347

                ****   MOLE-X-PROFILE    ****
  STAGE     PROPANE       BUTANE
    1    0.30215E-02   0.56793E-03
    2    0.96815E-02   0.39840E-02
    3    0.17905E-01   0.16881E-01
    4    0.23179E-01   0.18011E-01
    8    0.33236E-01   0.56956E-01
    9    0.34061E-01   0.82186E-01
   10    0.34231E-01   0.11903
   11    0.33631E-01   0.17055
   12    0.32152E-01   0.23839

                ****   MOLE-Y-PROFILE    ****
  STAGE     HYDROGEN      METHANE       ETHENE       ETHANE       PROPENE
    1    0.85037       0.91175E-01   0.54531E-01   0.33389E-02   0.57679E-03
```

2	0.28681	0.81930E-01	0.49016	0.56622E-01	0.82048E-01
3	0.24802	0.46470E-01	0.40389	0.61052E-01	0.23130
4	0.14753E-01	0.12746E-01	0.32312	0.64525E-01	0.55996
8	0.10145E-04	0.21713E-03	0.48772E-01	0.17561E-01	0.86637
9	0.20286E-05	0.85117E-04	0.29869E-01	0.12243E-01	0.87201
10	0.41785E-06	0.33681E-04	0.18084E-01	0.84496E-02	0.86095
11	0.87693E-07	0.13354E-04	0.10750E-01	0.57509E-02	0.83312
12	0.18640E-07	0.52725E-05	0.62255E-02	0.38410E-02	0.78742

**** MOLE-Y-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.10406E-04	0.76424E-06
2	0.20485E-02	0.38466E-03
3	0.65954E-02	0.26738E-02
4	0.17307E-01	0.75880E-02
8	0.31813E-01	0.35262E-01
9	0.33262E-01	0.52525E-01
10	0.34107E-01	0.78377E-01
11	0.34283E-01	0.11608
12	0.33668E-01	0.16885

**** K-VALUES ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	47.878	1.1762	0.78106E-01	0.40685E-01	0.47686E-02
2	19.667	3.2873	0.93325	0.67798	0.24262
3	17.519	3.7991	1.3019	0.98431	0.40828
4	7.9967	3.1019	1.6185	1.3612	0.79339
8	5.1233	2.6118	1.6680	1.4622	0.99759
9	4.9723	2.5850	1.6841	1.4737	1.0167
10	4.8774	2.5748	1.7102	1.4896	1.0367
11	4.7991	2.5720	1.7459	1.5104	1.0603
12	4.6992	2.5654	1.7872	1.5342	1.0885

**** K-VALUES ****

STAGE	PROPANE	BUTANE
1	0.34435E-02	0.13455E-02
2	0.21156	0.96536E-01
3	0.36837	0.15839
4	0.74670	0.42131
8	0.95719	0.61911
9	0.97659	0.63911
10	0.99641	0.65851
11	1.0195	0.68073
12	1.0473	0.70835

**** MASS-X-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.12525E-02	0.43501E-01	0.68509	0.86314E-01	0.17803
2	0.90301E-03	0.12280E-01	0.45249	0.77120E-01	0.43698
3	0.78404E-03	0.53907E-02	0.23908	0.51233E-01	0.65487
4	0.95697E-04	0.16962E-02	0.14411	0.36677E-01	0.76419
8	0.93919E-07	0.31379E-04	0.19299E-01	0.84968E-02	0.85981
9	0.19075E-07	0.12251E-04	0.11540E-01	0.57938E-02	0.83703
10	0.39395E-08	0.47869E-05	0.67668E-02	0.38907E-02	0.79711
11	0.82350E-09	0.18619E-05	0.38606E-02	0.25588E-02	0.73894
12	0.17431E-09	0.71868E-06	0.21299E-02	0.16407E-02	0.66340

**** MASS-X-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.46606E-02	0.11547E-02
2	0.13111E-01	0.71116E-02
3	0.21688E-01	0.26952E-01
4	0.26298E-01	0.26935E-01
8	0.34480E-01	0.77885E-01
9	0.34833E-01	0.11079
10	0.34430E-01	0.15780
11	0.33138E-01	0.22150
12	0.30895E-01	0.30193

**** MASS-Y-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.35477	0.30272	0.31660	0.20778E-01	0.50232E-02
2	0.27649E-01	0.62856E-01	0.65758	0.81420E-01	0.16511
3	0.20331E-01	0.30316E-01	0.46075	0.74652E-01	0.39580
4	0.82596E-03	0.56789E-02	0.25175	0.53885E-01	0.65441
8	0.48916E-06	0.83317E-04	0.32725E-01	0.12630E-01	0.87199
9	0.96396E-07	0.32189E-04	0.19752E-01	0.86779E-02	0.86500
10	0.19566E-07	0.12551E-04	0.11784E-01	0.59018E-02	0.84155
11	0.40368E-08	0.48920E-05	0.68867E-02	0.39489E-02	0.80057
12	0.84020E-09	0.18913E-05	0.39051E-02	0.25824E-02	0.74088

**** MASS-Y-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.94964E-04	0.91931E-05
2	0.43197E-02	0.10692E-02
3	0.11827E-01	0.63197E-02
4	0.21195E-01	0.12249E-01
8	0.33553E-01	0.49021E-01
9	0.34575E-01	0.71966E-01
10	0.34936E-01	0.10582
11	0.34521E-01	0.15407
12	0.33196E-01	0.21943

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	-131.22	19.170
2	19.170	63.974
3	63.974	109.59
4	131.01	151.69
8	177.91	183.46
9	183.46	189.39
10	189.39	196.50
11	196.50	205.24
12	205.24	205.24

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	21098.	22800.	619.95	8282.9	28.588	20.911
2	27246.	31046.	953.46	10248.	32.561	24.591
3	26875.	30675.	942.52	10612.	36.405	26.355

4	39449.	38085.	1574.9	6470.5	38.866	38.654
8	52992.	51628.	2274.3	7708.9	42.505	42.422
9	53837.	52473.	2319.0	7766.3	43.118	43.051
10	54152.	52788.	2336.0	7763.0	43.842	43.792
11	54375.	53011.	2347.5	7729.5	44.752	44.724
12	1364.0	0.0000	58.989	0.0000	45.891	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	34.031	2.7527	0.11472	0.10543E-01	14.770
2	28.576	3.0295	0.58216E-01	0.11099E-01	7.0114
3	28.514	2.8906	0.56979E-01	0.11519E-01	5.8932
4	25.048	5.8859	0.47095E-01	0.13253E-01	3.1884
8	23.301	6.6973	0.40905E-01	0.13920E-01	1.8705
9	23.216	6.7564	0.40664E-01	0.13994E-01	1.7748
10	23.182	6.7999	0.40656E-01	0.14067E-01	1.7437
11	23.163	6.8582	0.40838E-01	0.14157E-01	1.7299
12	23.124		0.41179E-01		1.6792

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.26317	2457.2	13742.
2	-7.7590	0.28575	3529.0	17837.
3	-1.1181	0.27895	3564.3	18042.
4	-2.7048	0.50212	3586.1	15698.
8	-.19927	0.55029	4896.0	19950.
9	-.95711E-01	0.55350	4975.9	20187.
10	-.31175E-01	0.55560	5001.5	20243.
11	-.13731E-01	0.55814	5013.0	20242.
12	-.50694E-01		0.0000	0.0000

```
***********************************
***** TRAY SIZING CALCULATIONS *****
***********************************


******************
*** SECTION   1 ***
******************
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STARTING STAGE NUMBER 2
ENDING STAGE NUMBER 10
FLOODING CALCULATION METHOD GLITSCH6

DESIGN PARAMETERS

PEAK CAPACITY FACTOR		1.00000
SYSTEM FOAMING FACTOR		1.00000
FLOODING FACTOR		0.80000
MINIMUM COLUMN DIAMETER	FT	1.00000
MINIMUM DC AREA/COLUMN AREA		0.100000
HOLE AREA/ACTIVE AREA		0.100000
DOWNCOMER DESIGN BASIS		EQUAL FLOW PATH LENGTH

TRAY SPECIFICATIONS

TRAY TYPE		SIEVE
NUMBER OF PASSES		1
TRAY SPACING	FT	1.50000

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER		10
COLUMN DIAMETER	FT	4.12467
DC AREA/COLUMN AREA		0.21155
DOWNCOMER VELOCITY	FT/SEC	0.22956
FLOW PATH LENGTH PER PANEL	FT	1.94341
SIDE DOWNCOMER WIDTH	FT	1.09063
SIDE WEIR LENGTH	FT	3.63814
CENTER DOWNCOMER WIDTH	FT	0.0
CENTER WEIR LENGTH	FT	MISSING
OFF-CENTER DOWNCOMER WIDTH	FT	0.0
OFF-CENTER SHORT WEIR LENGTH	FT	MISSING
OFF-CENTER LONG WEIR LENGTH	FT	MISSING
TRAY CENTER TO OCDC CENTER	FT	0.0

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	FT	SQFT	SQFT	SQFT
2	4.1247	13.362	7.7086	2.8267
3	4.1247	13.362	7.7086	2.8267
4	4.1247	13.362	7.7086	2.8267
5	4.1247	13.362	7.7086	2.8267

6	4.1247	13.362	7.7086	2.8267
7	4.1247	13.362	7.7086	2.8267
8	4.1247	13.362	7.7086	2.8267
9	4.1247	13.362	7.7086	2.8267
10	4.1247	13.362	7.7086	2.8267

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
2	41.32	0.6385E-01	0.6124	37.68
3	41.40	0.6219E-01	0.6065	37.32
4	51.12	0.9134E-01	0.9453	58.18
5	59.92	0.9561E-01	1.094	67.32
6	67.72	0.9858E-01	1.206	74.22
7	73.27	0.1005	1.287	79.18
8	76.92	0.1018	1.340	82.47
9	78.99	0.1026	1.369	84.26
10	80.00	0.1031	1.381	84.97

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.1483	0.5125	0.4019	22.13
3	0.1478	0.5135	0.3992	23.26
4	0.2003	0.4319	0.4324	28.82
5	0.2358	0.4202	0.4065	34.77
6	0.2608	0.4140	0.3908	39.19
7	0.2782	0.4105	0.3811	43.03
8	0.2894	0.4084	0.3752	45.70
9	0.2953	0.4073	0.3724	47.14
10	0.2973	0.4067	0.3717	47.63

BLOCK: DEPROP MODEL: RADFRAC

INLETS - DP-FEED STAGE 16
OUTLETS - C2-WASTE STAGE 1
BUTANE STAGE 30
PROPENE STAGE 10
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			

MOLE(LBMOL/HR)	41.9268	41.9268	0.169472E-15
MASS(LB/HR)	1841.64	1841.64	0.628359E-06
ENTHALPY(BTU/HR)	-438973.	-544581.	0.193925

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.245077E-01	LB/HR
PRODUCT STREAMS CO2E	0.245084E-01	LB/HR
NET STREAMS CO2E PRODUCTION	0.791071E-06	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.791071E-06	LB/HR

****
**** INPUT DATA ****
****

**** INPUT PARAMETERS ****

NUMBER OF STAGES	30
ALGORITHM OPTION	STANDARD
ABSORBER OPTION	NO
INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	BROYDEN
DESIGN SPECIFICATION METHOD	NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	70
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	0.000100000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST		1.00000
MASS REFLUX RATIO		42.0000
MASS DISTILLATE RATE	LB/HR	96.0000

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 150.000

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS		
	C2-WASTE	BUTANE	PROPENE
COMPONENT:			
HYDROGEN	.99680	0.0000	.31966E-02
METHANE	.98015	0.0000	.19847E-01
ETHENE	.91591	.12254E-10	.84086E-01
ETHANE	.87267	.65823E-08	.12733
PROPENE	.85133E-02	.55470E-01	.93602
PROPANE	.20561E-02	.21106	.78688
BUTANE	.11597E-10	.99880	.11986E-02

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	-11.3169
BOTTOM STAGE TEMPERATURE	F	149.115
TOP STAGE LIQUID FLOW	LBMOL/HR	122.190
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	9.05243
TOP STAGE VAPOR FLOW	LBMOL/HR	3.10094
BOILUP VAPOR FLOW	LBMOL/HR	78.0805
MOLAR REFLUX RATIO		39.4042
MOLAR BOILUP RATIO		8.62537
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-702,345.
REBOILER DUTY	BTU/HR	596,741.

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT	0.48729E-04	STAGE= 28	
BUBBLE POINT	0.21325E-03	STAGE= 2	
COMPONENT MASS BALANCE	0.72413E-05	STAGE= 15	COMP=ETHENE
ENERGY BALANCE	0.12987E-03	STAGE= 1	

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

			ENTHALPY		
STAGE	TEMPERATURE	PRESSURE	BTU/LBMOL		HEAT DUTY
	F	PSIA	LIQUID	VAPOR	BTU/HR

1	-11.317	150.00	-30174.	-30181.	-.70235+06
2	11.548	153.00	-19319.	-24570.	
3	37.506	153.14	-9140.1	-13583.	
9	69.004	153.98	-275.34	5092.4	
10	69.163	154.12	-426.14	4994.3	
11	69.323	154.26	-636.44	4846.9	
14	70.935	154.68	-2246.9	4223.3	
15	73.234	154.82	-4350.7	3606.8	
16	77.314	154.96	-6755.2	3438.2	
17	78.159	155.10	-6699.2	3802.5	
29	125.06	156.78	-38007.	-15738.	
30	149.11	156.92	-48418.	-29157.	.59674+06

STAGE	FLOW RATE LBMOL/HR		FEED RATE LBMOL/HR			PRODUCT RATE LBMOL/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	122.2	3.101					3.1009
2	113.5	125.3					
3	110.4	116.6					
9	112.6	115.6					
10	112.6	115.7			29.7734		
11	82.79	115.7					
14	81.58	115.2					
15	79.78	114.5		20.6520			
16	101.3	92.00	21.2747				
17	101.5	92.25					
29	87.13	81.52					
30	9.052	78.08				9.0524	

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR		FEED RATE LB/HR			PRODUCT RATE LB/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	4032.	96.00					96.0000
2	4126.	4128.					
3	4340.	4222.					
9	4725.	4817.					
10	4727.	4821.			1250.0000		
11	3478.	4823.					
14	3455.	4816.					
15	3421.	4801.		867.8974			
16	4421.	3899.	973.7426				
17	4433.	3925.					
29	4508.	3877.					

30 495.6 4013. 495.6388

**** MOLE-X-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.40717E-09	0.21515E-05	0.32066E-01	0.71924	0.24581
2	0.14449E-10	0.24309E-06	0.13825E-01	0.46176	0.51720
3	0.11363E-10	0.60778E-07	0.50256E-02	0.22612	0.75684
9	0.12640E-10	0.40701E-07	0.58825E-03	0.13329E-01	0.95778
10	0.12664E-10	0.40734E-07	0.58640E-03	0.12985E-01	0.95503
11	0.12690E-10	0.40779E-07	0.58558E-03	0.12861E-01	0.95123
14	0.12848E-10	0.40897E-07	0.57370E-03	0.12706E-01	0.92509
15	0.13024E-10	0.40915E-07	0.55475E-03	0.12506E-01	0.89217
16	0.35426E-12	0.57849E-08	0.20836E-03	0.64963E-02	0.85630
17	0.49594E-14	0.45683E-09	0.54011E-04	0.24146E-02	0.85798
29	0.42544E-36	0.24972E-22	0.19842E-11	0.92900E-08	0.35611
30	0.76694E-38	0.18066E-23	0.28107E-12	0.22078E-08	0.18615

**** MOLE-X-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.28888E-02	0.40331E-09
2	0.72111E-02	0.39609E-08
3	0.12019E-01	0.24252E-07
9	0.28219E-01	0.79075E-04
10	0.31117E-01	0.28693E-03
11	0.34284E-01	0.10392E-02
14	0.39792E-01	0.21834E-01
15	0.39681E-01	0.55092E-01
16	0.39715E-01	0.97277E-01
17	0.42228E-01	0.97320E-01
29	0.47826E-01	0.59607
30	0.27451E-01	0.78640

**** MOLE-Y-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.37916E-07	0.19315E-04	0.61328E-01	0.85447	0.83400E-01
2	0.13355E-08	0.25763E-05	0.32790E-01	0.72258	0.24179
3	0.10225E-08	0.75034E-06	0.15088E-01	0.47220	0.50567
9	0.10289E-08	0.55751E-06	0.22230E-02	0.36824E-01	0.93603
10	0.10286E-08	0.55734E-06	0.22163E-02	0.35876E-01	0.93435
11	0.10285E-08	0.55732E-06	0.22144E-02	0.35538E-01	0.93166
14	0.10326E-08	0.55943E-06	0.22173E-02	0.35485E-01	0.92060
15	0.10397E-08	0.56306E-06	0.22230E-02	0.35585E-01	0.91008
16	0.27922E-10	0.80415E-07	0.87922E-03	0.19093E-01	0.91259
17	0.38902E-12	0.63526E-08	0.22881E-03	0.71338E-02	0.92206
29	0.28667E-34	0.37524E-21	0.13386E-10	0.37525E-07	0.59532
30	0.47388E-36	0.27658E-22	0.21817E-11	0.10111E-07	0.37581

**** MOLE-Y-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.78067E-03	0.26655E-10
2	0.28366E-02	0.39399E-09
3	0.70400E-02	0.38563E-08
9	0.24903E-01	0.21169E-04
10	0.27483E-01	0.76956E-04
11	0.30304E-01	0.27924E-03
14	0.35703E-01	0.59971E-02
15	0.36478E-01	0.15637E-01
16	0.38151E-01	0.29286E-01
17	0.40918E-01	0.29655E-01
29	0.72061E-01	0.33262
30	0.50188E-01	0.57400

**** K-VALUES ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	93.273	8.9831	1.9134	1.1881	0.33925
2	92.704	10.615	2.3735	1.5654	0.46733
3	90.066	12.352	3.0029	2.0887	0.66809
9	81.408	13.698	3.7792	2.7627	0.97728
10	81.231	13.683	3.7797	2.7630	0.97835
11	81.054	13.667	3.7816	2.7633	0.97943
14	80.365	13.679	3.8652	2.7927	0.99514
15	79.817	13.760	4.0078	2.8454	1.0201
16	78.789	13.898	4.2203	2.9388	1.0657
17	78.410	13.902	4.2370	2.9542	1.0747
29	67.334	15.020	6.7449	4.0384	1.6716
30	61.775	15.307	7.7614	4.5794	2.0188

**** K-VALUES ****

STAGE	PROPANE	BUTANE
1	0.27012	0.66043E-01
2	0.39318	0.99339E-01
3	0.58571	0.15896
9	0.88249	0.26770
10	0.88322	0.26820
11	0.88389	0.26869
14	0.89724	0.27467
15	0.91926	0.28385
16	0.96061	0.30109
17	0.96898	0.30475
29	1.5067	0.55809
30	1.8282	0.72992

**** MASS-X-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.24875E-10	0.10460E-05	0.27261E-01	0.65541	0.31346
2	0.80122E-12	0.10727E-06	0.10668E-01	0.38193	0.59866
3	0.58257E-12	0.24799E-07	0.35857E-02	0.17293	0.81001
9	0.60713E-12	0.15558E-07	0.39319E-03	0.95498E-02	0.96030
10	0.60807E-12	0.15565E-07	0.39183E-03	0.92999E-02	0.95723
11	0.60904E-12	0.15575E-07	0.39110E-03	0.92069E-02	0.95297
14	0.61157E-12	0.15492E-07	0.38003E-03	0.90217E-02	0.91920
15	0.61219E-12	0.15305E-07	0.36289E-03	0.87683E-02	0.87540
16	0.16364E-13	0.21266E-08	0.13395E-03	0.44762E-02	0.82570
17	0.22879E-15	0.16772E-09	0.34675E-04	0.16616E-02	0.82624
29	0.16576E-37	0.77429E-23	0.10759E-11	0.53991E-08	0.28963
30	0.28237E-39	0.52934E-24	0.14401E-12	0.12125E-08	0.14307

**** MASS-X-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.38604E-02	0.71040E-09
2	0.87466E-02	0.63326E-08
3	0.13480E-01	0.35851E-07
9	0.29648E-01	0.10951E-03
10	0.32683E-01	0.39723E-03
11	0.35992E-01	0.14380E-02
14	0.41432E-01	0.29966E-01
15	0.40801E-01	0.74666E-01
16	0.40130E-01	0.12956
17	0.42614E-01	0.12945
29	0.40761E-01	0.66961
30	0.22109E-01	0.83483

**** MASS-Y-PROFILE ****

STAGE	HYDROGEN	METHANE	ETHENE	ETHANE	PROPENE
1	0.24689E-08	0.10009E-04	0.55574E-01	0.82994	0.11336
2	0.81711E-10	0.12545E-05	0.27920E-01	0.65947	0.30881
3	0.56922E-10	0.33242E-06	0.11689E-01	0.39211	0.58762
9	0.49792E-10	0.21470E-06	0.14971E-02	0.26581E-01	0.94553
10	0.49755E-10	0.21455E-06	0.14919E-02	0.25885E-01	0.94344
11	0.49735E-10	0.21447E-06	0.14901E-02	0.25633E-01	0.94043
14	0.49808E-10	0.21475E-06	0.14884E-02	0.25532E-01	0.92697
15	0.49967E-10	0.21535E-06	0.14868E-02	0.25509E-01	0.91299
16	0.13280E-11	0.30436E-07	0.58193E-03	0.13545E-01	0.90602
17	0.18431E-13	0.23951E-08	0.15086E-03	0.50414E-02	0.91189
29	0.12150E-35	0.12657E-21	0.78953E-11	0.23724E-07	0.52671
30	0.18589E-37	0.86340E-23	0.11910E-11	0.59162E-08	0.30773

**** MASS-Y-PROFILE ****

STAGE	PROPANE	BUTANE
1	0.11120E-02	0.50044E-10
2	0.37965E-02	0.69505E-09
3	0.85730E-02	0.61897E-08
9	0.26361E-01	0.29536E-04
10	0.29080E-01	0.10733E-03
11	0.32054E-01	0.38932E-03
14	0.37672E-01	0.83408E-02
15	0.38348E-01	0.21668E-01
16	0.39690E-01	0.40160E-01
17	0.42405E-01	0.40509E-01
29	0.66811E-01	0.40648
30	0.43065E-01	0.64921

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	-11.317	11.548
2	11.548	37.506
3	37.506	55.248
9	69.004	69.163
10	69.163	69.323

11	69.323	69.544
14	70.935	73.234
15	73.234	78.327
16	77.314	78.159
17	78.159	78.529
29	125.06	149.11
30	149.11	149.11

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	4032.0	4128.0	132.27	3470.0	32.998	32.947
2	4125.8	4221.8	130.54	3393.8	36.355	36.212
3	4340.4	4436.4	135.20	3388.5	39.319	39.090
9	4725.2	4821.2	147.99	3486.8	41.970	41.675
10	4727.2	4823.2	148.10	3484.5	41.984	41.688
11	3477.6	4823.6	108.97	3481.5	42.004	41.702
14	3454.9	4800.9	108.15	3464.4	42.350	41.946
15	3421.4	4767.4	106.86	3451.0	42.886	42.320
16	4421.1	3925.4	137.82	2811.1	43.640	42.550
17	4433.2	3937.6	138.28	2813.6	43.697	42.614
29	4508.2	4012.6	140.47	2638.3	51.740	51.390
30	495.64	0.0000	15.636	0.0000	54.752	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	30.484	1.1896	0.91044E-01	0.85703E-02	8.8278
2	31.605	1.2440	0.92216E-01	0.88116E-02	8.8963
3	32.103	1.3093	0.89882E-01	0.89503E-02	8.6357
9	31.928	1.3827	0.84280E-01	0.90493E-02	7.7666
10	31.920	1.3842	0.84268E-01	0.90513E-02	7.7598
11	31.913	1.3855	0.84276E-01	0.90541E-02	7.7532
14	31.945	1.3858	0.84630E-01	0.90953E-02	7.7035
15	32.017	1.3815	0.85230E-01	0.91474E-02	7.6385
16	32.080	1.3964	0.85769E-01	0.91384E-02	7.6670
17	32.059	1.3995	0.85616E-01	0.91412E-02	7.6377
29	32.094	1.5209	0.92279E-01	0.95780E-02	7.0751
30	31.698		0.93530E-01		6.4649

	MARANGONI INDEX	FLOW PARAM	QR	REDUCED F-FACTOR
STAGE	DYNE/CM		CUFT/HR	(LB-CUFT)**.5/HR

1		0.19295	699.27	3784.7
2	0.68568E-01	0.19388	686.97	3785.2
3	-.26063	0.19758	698.70	3877.2
9	-.10059E-01	0.20396	741.85	4100.1
10	-.68579E-02	0.20410	741.88	4099.6
11	-.65952E-02	0.15022	741.68	4098.0
14	-.28101E-01	0.14988	737.74	4078.3
15	-.65037E-01	0.14907	732.82	4056.1
16	-.62188E-01	0.23498	599.69	3321.9
17	-.29329E-01	0.23523	601.12	3328.5
29	-.62463	0.24458	588.44	3253.7
30	-.61015		0.0000	0.0000

```
************************************
***** TRAY SIZING CALCULATIONS *****
************************************


*******************
*** SECTION   1 ***
*******************

STARTING STAGE NUMBER                          2
ENDING STAGE NUMBER                           29
FLOODING CALCULATION METHOD                   GLITSCH6

DESIGN PARAMETERS
-----------------
PEAK CAPACITY FACTOR                     1.00000
SYSTEM FOAMING FACTOR                    1.00000
FLOODING FACTOR                          0.80000
MINIMUM COLUMN DIAMETER       FT         1.00000
MINIMUM DC AREA/COLUMN AREA              0.100000
HOLE AREA/ACTIVE AREA                    0.100000
DOWNCOMER DESIGN BASIS                   EQUAL FLOW PATH LENGTH

TRAY SPECIFICATIONS
-------------------
TRAY TYPE                          SIEVE
NUMBER OF PASSES                       1
TRAY SPACING          FT         1.50000
```

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER		10
COLUMN DIAMETER	FT	1.10184
DC AREA/COLUMN AREA		0.13766
DOWNCOMER VELOCITY	FT/SEC	0.31341
FLOW PATH LENGTH PER PANEL	FT	0.67136
SIDE DOWNCOMER WIDTH	FT	0.21524
SIDE WEIR LENGTH	FT	0.87368
CENTER DOWNCOMER WIDTH	FT	0.0
CENTER WEIR LENGTH	FT	MISSING
OFF-CENTER DOWNCOMER WIDTH	FT	0.0
OFF-CENTER SHORT WEIR LENGTH	FT	MISSING
OFF-CENTER LONG WEIR LENGTH	FT	MISSING
TRAY CENTER TO OCDC CENTER	FT	0.0

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	FT	SQFT	SQFT	SQFT
2	1.1018	0.95351	0.69099	0.13126
3	1.1018	0.95351	0.69099	0.13126
4	1.1018	0.95351	0.69099	0.13126
5	1.1018	0.95351	0.69099	0.13126
6	1.1018	0.95351	0.69099	0.13126
7	1.1018	0.95351	0.69099	0.13126
8	1.1018	0.95351	0.69099	0.13126
9	1.1018	0.95351	0.69099	0.13126
10	1.1018	0.95351	0.69099	0.13126
11	1.1018	0.95351	0.69099	0.13126
12	1.1018	0.95351	0.69099	0.13126
13	1.1018	0.95351	0.69099	0.13126
14	1.1018	0.95351	0.69099	0.13126
15	1.1018	0.95351	0.69099	0.13126
16	1.1018	0.95351	0.69099	0.13126
17	1.1018	0.95351	0.69099	0.13126
18	1.1018	0.95351	0.69099	0.13126
19	1.1018	0.95351	0.69099	0.13126
20	1.1018	0.95351	0.69099	0.13126
21	1.1018	0.95351	0.69099	0.13126
22	1.1018	0.95351	0.69099	0.13126
23	1.1018	0.95351	0.69099	0.13126
24	1.1018	0.95351	0.69099	0.13126
25	1.1018	0.95351	0.69099	0.13126
26	1.1018	0.95351	0.69099	0.13126

27	1.1018	0.95351	0.69099	0.13126
28	1.1018	0.95351	0.69099	0.13126
29	1.1018	0.95351	0.69099	0.13126

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
2	73.59	0.7423E-01	0.6231	38.34
3	75.06	0.7730E-01	0.6318	38.88
4	77.49	0.8039E-01	0.6547	40.29
5	78.98	0.8211E-01	0.6694	41.20
6	79.62	0.8285E-01	0.6762	41.61
7	79.87	0.8312E-01	0.6788	41.77
8	79.96	0.8322E-01	0.6798	41.84
9	79.99	0.8325E-01	0.6802	41.86
10	80.00	0.8325E-01	0.6804	41.87
11	78.87	0.8209E-01	0.6492	39.95
12	78.83	0.8203E-01	0.6487	39.92
13	78.71	0.8190E-01	0.6475	39.85
14	78.45	0.8161E-01	0.6445	39.66
15	77.90	0.8103E-01	0.6384	39.28
16	65.21	0.6699E-01	0.5596	34.43
17	65.37	0.6714E-01	0.5610	34.52
18	65.44	0.6720E-01	0.5616	34.56
19	65.46	0.6722E-01	0.5619	34.58
20	65.48	0.6723E-01	0.5621	34.59
21	65.49	0.6724E-01	0.5623	34.60
22	65.50	0.6724E-01	0.5624	34.61
23	65.50	0.6724E-01	0.5625	34.62
24	65.46	0.6721E-01	0.5624	34.61
25	65.31	0.6708E-01	0.5613	34.54
26	64.90	0.6675E-01	0.5579	34.33
27	64.05	0.6614E-01	0.5510	33.91
28	63.30	0.6581E-01	0.5450	33.54
29	64.36	0.6705E-01	0.5537	34.07

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.2227	0.5637	0.2214	50.13
3	0.2304	0.5671	0.2179	51.71
4	0.2405	0.5667	0.2137	53.90
5	0.2465	0.5660	0.2114	55.60

6	0.2491	0.5656	0.2105	56.21
7	0.2501	0.5654	0.2102	56.46
8	0.2506	0.5653	0.2101	56.55
9	0.2507	0.5652	0.2100	56.59
10	0.2508	0.5651	0.2101	56.61
11	0.2044	0.5650	0.2101	56.37
12	0.2043	0.5650	0.2102	56.35
13	0.2039	0.5651	0.2104	56.30
14	0.2030	0.5653	0.2108	56.17
15	0.2009	0.5659	0.2115	55.92
16	0.2172	0.5662	0.2426	45.92
17	0.2179	0.5661	0.2423	46.07
18	0.2182	0.5660	0.2421	46.13
19	0.2184	0.5659	0.2421	46.16
20	0.2185	0.5658	0.2421	46.17
21	0.2186	0.5657	0.2421	46.18
22	0.2187	0.5656	0.2422	46.18
23	0.2187	0.5655	0.2422	46.17
24	0.2186	0.5655	0.2423	46.05
25	0.2181	0.5655	0.2427	45.93
26	0.2166	0.5658	0.2437	45.57
27	0.2136	0.5665	0.2458	44.89
28	0.2118	0.5670	0.2480	44.54
29	0.2178	0.5654	0.2463	46.24

BUTANE C2-FEED C2-OUT C2-WASTE C2H4-REC

STREAM ID	BUTANE	C2-FEED	C2-OUT	C2-WASTE	C2H4-REC
FROM :	DEPROP	B1	DEETH	DEPROP	DEMETH
TO :	----	C2-SPLIT	B1	----	DEETH
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	VAPOR	LIQUID
COMPONENTS: LBMOL/HR					
HYDROGEN	0.0	8.1869-03	8.1869-03	1.1758-07	1.3033
METHANE	1.6354-23	0.4507	0.4507	5.9895-05	5.6878
ETHENE	2.5443-12	49.9360	49.9360	0.1902	51.2248
ETHANE	1.9986-08	3.0549	3.0549	2.6497	6.0211
PROPENE	1.6851	7.0919-08	7.0919-08	0.2586	8.8741
PROPANE	0.2485	6.7261-11	6.7261-11	2.4208-03	0.2217
BUTANE	7.1189	1.9388-15	1.9388-15	8.2655-11	4.1672-02
TOTAL FLOW:					
LBMOL/HR	9.0524	53.4498	53.4498	3.1009	73.3744
LB/HR	495.6388	1499.9994	1499.9994	96.0001	2097.5991
CUFT/HR	15.6363	51.9239	51.5214	83.1029	61.6375
STATE VARIABLES:					
TEMP F	149.1145	-40.9305	-44.1624	-11.3169	-131.2174
PRES PSIA	156.9200	300.0000	203.5600	150.0000	550.0000
VFRAC	0.0	0.0	0.0	1.0000	0.0
LFRAC	1.0000	1.0000	1.0000	0.0	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-4.8418+04	1.2767+04	1.2709+04	-3.0181+04	3517.1063
BTU/LB	-884.3223	454.9390	452.8657	-974.8802	123.0289
BTU/HR	-4.3830+05	6.8241+05	6.7930+05	-9.3589+04	2.5807+05
ENTROPY:					
BTU/LBMOL-R	-89.8621	-32.7966	-32.8967	-45.5229	-39.5110
BTU/LB-R	-1.6413	-1.1686	-1.1722	-1.4705	-1.3821
DENSITY:					
LBMOL/CUFT	0.5789	1.0294	1.0374	3.7314-02	1.1904
LB/CUFT	31.6980	28.8884	29.1141	1.1552	34.0312
AVG MW	54.7520	28.0637	28.0637	30.9584	28.5876

DE-BOT DM-BOT DP-FEED ETHANE ETHYLENE

STREAM ID	DE-BOT	DM-BOT	DP-FEED	ETHANE	ETHYLENE
FROM :	DEETH	DEMETH	HEAVYMIX	C2-SPLIT	C2-SPLIT
TO :	HEAVYMIX	HEAVYMIX	DEPROP	----	----

SUBSTREAM: MIXED

PHASE:	LIQUID	LIQUID	MIXED	LIQUID	VAPOR
COMPONENTS: LBMOL/HR					
HYDROGEN	1.3272-24	1.1795-07	1.1795-07	1.7883-25	8.1869-03
METHANE	3.8434-11	6.1106-05	6.1106-05	5.4964-12	0.4507
ETHENE	0.1041	0.1036	0.2076	0.1754	49.7607
ETHANE	2.9617	7.4427-02	3.0362	2.8294	0.2255
PROPENE	8.8739	21.5042	30.3781	7.0919-08	3.6801-16
PROPANE	0.2217	0.9557	1.1774	6.7261-11	3.4566-20
BUTANE	4.1671-02	7.0857	7.1274	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	12.2031	29.7236	41.9268	3.0048	50.4450
LB/HR	477.5974	1364.0427	1841.6401	89.9994	1410.0000
CUFT/HR	15.4960	58.9891	443.0044	3.4553	595.3505
STATE VARIABLES:					
TEMP F	57.4754	205.2431	103.2282	17.2805	-20.5717
PRES PSIA	207.2000	554.4000	207.2000	296.2200	290.0000
VFRAC	0.0	0.0	0.4240	0.0	1.0000
LFRAC	1.0000	1.0000	0.5760	1.0000	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-9828.5061	-1.0733+04	-1.0470+04	-3.8271+04	2.0210+04
BTU/LB	-251.1288	-233.8889	-238.3598	-1277.7355	723.0350
BTU/HR	-1.1994+05	-3.1903+05	-4.3897+05	-1.1500+05	1.0195+06
ENTROPY:					
BTU/LBMOL-R	-52.2978	-56.1697	-54.1629	-56.6729	-21.6822
BTU/LB-R	-1.3363	-1.2240	-1.2331	-1.8921	-0.7757
DENSITY:					
LBMOL/CUFT	0.7875	0.5039	9.4642-02	0.8696	8.4732-02
LB/CUFT	30.8207	23.1236	4.1572	26.0470	2.3684
AVG MW	39.1373	45.8908	43.9252	29.9520	27.9512

H2-CH4-1 H2-CH4-2 PROPENE SEP-FEED

STREAM ID	H2-CH4-1	H2-CH4-2	PROPENE	SEP-FEED
FROM :	DEMETH	DEETH	DEPROP	----
TO :	----	----	----	DEMETH

SUBSTREAM: MIXED

PHASE:	VAPOR	VAPOR	LIQUID	VAPOR
COMPONENTS: LBMOL/HR				
HYDROGEN	299.6040	1.2951	3.7705-10	300.9073
METHANE	32.1232	5.2370	1.2128-06	37.8110
ETHENE	19.2126	1.1850	1.7459-02	70.5410
ETHANE	1.1764	4.3939-03	0.3866	7.2719

PROPENE	0.2032	1.0595-14	28.4343	30.5815
PROPANE	3.6662-03	2.1741-18	0.9265	1.1810
BUTANE	2.6926-04	2.5603-24	8.5428-03	7.1277
TOTAL FLOW:				
LBMOL/HR	352.3234	7.7215	29.7734	455.4214
LB/HR	1702.3991	120.0022	1250.0000	5164.0430
CUFT/HR	2242.3848	120.6316	39.1603	5275.4676
STATE VARIABLES:				
TEMP F	-131.2174	-129.7919	69.1628	142.5000
PRES PSIA	550.0000	200.0000	154.1200	555.0000
VFRAC	1.0000	1.0000	0.0	1.0000
LFRAC	0.0	0.0	1.0000	0.0
SFRAC	0.0	0.0	0.0	0.0
ENTHALPY:				
BTU/LBMOL	-3337.9202	-2.0170+04	-426.1427	355.9486
BTU/LB	-690.8059	-1297.8502	-10.1502	31.3914
BTU/HR	-1.1760+06	-1.5574+05	-1.2688+04	1.6211+05
ENTROPY:				
BTU/LBMOL-R	-12.3661	-22.8672	-51.8721	-12.2323
BTU/LB-R	-2.5593	-1.4714	-1.2355	-1.0788
DENSITY:				
LBMOL/CUFT	0.1571	6.4009-02	0.7603	8.6328-02
LB/CUFT	0.7592	0.9948	31.9201	0.9789
AVG MW	4.8319	15.5414	41.9838	11.3390