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Propane Dehydrogenation by Autothermal Reforming

Jeffrey W. Barsamian  
University of Pennsylvania, jbars@seas.upenn.edu

Jayant A. Rao  
University of Pennsylvania, jayrao@seas.upenn.edu

Patrick J. Staiber  
University of Pennsylvania, stpat@seas.upenn.edu

Eric Wamakima  
University of Pennsylvania, wamakima@seas.upenn.edu

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Abstract
The proposed design is for the production of propene through propane dehydrogenation using Thyssen Krupp's STAR technology and a hybrid membrane separation. The plant has a capacity of 700 kT/yr and will be located in the Middle East. At current propane/propene prices, the use of Thyssen Krupp's STAR process and hybrid membrane separation is not economical and has a negative IRR. The NPV of this project at current market prices is -$865MM. However, economic feasibility depends on volatile market conditions. The process begins with the oxydehydrogenation section, consisting of four reformers connected to four oxyreactors that are cycled to allow for regeneration of the 0.2-0.6%Pt- Sn/ZnAl_2O_5 catalyst. In order to produce polymer grade propene, a separation is needed following dehydrogenation. Separation operations include adsorption, MEA absorption system, distillation, and a hybrid distillation/membrane C3 splitter.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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Hello Dr. Gorte and Professor Fabiano,

Enclosed you will find a proposed process design for the industrial production of polymer-grade propene through the oxydehydrogenation of propane as proposed by Mr. Wismer. The presence of oxygen as a feed results in an increased conversion of propane in the second reactor as well as the exothermic conversion of the hydrogen byproduct which allows for autothermal reforming.

The design uses technology licensed from the STAR process by Thyssen Krupp and involves the dehydrogenation of propane over a .2-.6%Pt-Sn/ZnAl₂O₅ catalyst in the presence of steam. The effluent is then sent to a second reactor along with pure oxygen. Conventional propane dehydrogenation requires considerable heat to satisfy the endothermic heat of reaction and the conversion per pass is equilibrium limited. The contents are taken to an adsorption column to remove water from the system. After this step, the product stream is sent to an MEA absorption system to remove carbon dioxide and then another distillation column to remove hydrogen, carbon monoxide and light components. The resulting stream of C3 hydrocarbons is then sent to a novel hybrid system consisting of a distillation column and membrane separation to separate the propane and propene. The proposed plant with be located in the Middle East and has the capacity to produce 700 kT/yr of polymer grade propene.

This report contains detailed process design, economic analysis, and conclusions and recommendations for the implementation of the plant. At current raw material costs, the proposed design is economically feasible at a propene price of $0.43. At current propene prices, the estimated IRR is negative and the NPV is -$865,000,000. The continuous operations in this process were modeled using Aspen Plus v8.6. Cost estimates for the equipment were obtained using the equations contained in Process Design Principles, 3rd Edition, by Seider, Seader, Lewin and Widagdo.

Thank you for the assistance afforded to us during this project.

Sincerely,

Jeff Barsamian  
Jayant Rao

Patrick Staiber  
Eric Wamakima
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Abstract

The proposed design is for the production of propene through propane dehydrogenation using Thyssen Krupp’s STAR technology and a hybrid membrane separation. The plant has a capacity of 700 kT/yr and will be located in the Middle East. At current propane/propene prices, the use of Thyssen Krupp’s STAR process and hybrid membrane separation is not economical and has a negative IRR. The NPV of this project at current market prices is -$865MM. However, economic feasibility depends on volatile market conditions.

The process begins with the oxydehydrogenation section, consisting of four reformers connected to four oxyreactors that are cycled to allow for regeneration of the 0.2-0.6%Pt-Sn/ZnAl$_2$O$_5$ catalyst. In order to produce polymer grade propene, a separation is needed following dehydrogenation. Separation operations include adsorption, MEA absorption system, distillation, and a hybrid distillation/membrane C3 splitter.
Introduction

As demand increases for propene, the basis of the bulk polymer polypropylene, there has been significant research on alternatives to traditional propene production. Historically, propylene has been supplied a by product of refinery catalytic crackers and olefin plants that use naphtha or gas oil feedstock. However, in recent years, the decline in US gasoline consumption combined with the displacement of naphtha by ethane as a feedstock for olefin crackers has led to a decline in by-product propene production. These trends are expected to continue for the foreseeable future as new ethane-supplied crackers come on stream. As a result, propene will be increasingly supplied by on-purpose production. Although ethylene metathesis may play a bigger role in the future if ethylene prices drop as expected, the current preferred on-purpose route is propane dehydrogenation. This has typically been done in catalytic high temperature reactors.

Propane dehydrogenation requires considerable heat to satisfy the endothermic heat of reaction and the conversion per pass is equilibrium limited. Additionally, the separation of propane and propene is very energy intensive. In 2014, Thyssen Krupp developed the STAR process to combat these issues. This technology uses oxydehydrogenation as an alternative to direct dehydrogenation. In this technology, oxygen is co-fed to the reactor to react exothermically with the hydrogen produced by dehydrogenation (Herauville, 2012). Thus, the heat of combustion can be used to supply heat for the dehydrogenation reaction. Additionally, the consumption of hydrogen allows the equilibrium conversion of propane to propene to increase. The higher propylene content of the reactor allows for a less energy intensive C3 separation.

Current methods of the C3 separation involved in propane dehydrogenation processes are very energy intensive as well. Conventional distillation can require up to 200 theoretical stages.
and reflux ratios greater than 10. One promising alternative to distillation is membrane separation. A recent membrane development is to use a composite of resins and molecular sieves. Although not commercially available, ZIF-8, is showing promise in both C3 splitting and CO2 purification. There has been some indication that a hybrid process using both distillation and membranes may be optimal. This project attempts to quantify the feasibility of this system.

There are five licensed technologies for propane dehydrogenation: CATOFIN from Lummus Technology, Oleflex from UOP, Fluidized Bed Dehydrogenation from Snamprogetti, STAR process from Thyssen Krupp Udhe, and PDH from Linde/BASF. The main differences between these technologies are the type of catalyst, regeneration methods, reactor design, and methods used to increase conversion. Although all these technologies have their strengths and weaknesses, the scope of this project was to evaluate one of these technologies. This project evaluates the potential of the STAR process and a hybrid membrane separation to produce propene.

The process begins with the oxydehydration section, consisting of four reformer-oxyreactor complexes that are cycled to allow for catalyst regeneration. Various separations are performed after to get a polymer grade purity (>99.5%). Separation operations include a water adsorption system to recycle water, monoethanolamine CO1 capture system, distillation column to recover hydrogen and light hydrocarbons and a hybrid membrane C3 splitter. The NPV and IRR of this process is highly sensitive to the price margin between propane and propene. The price margin is currently relatively small for propene and propane at current market conditions, making the process uneconomical. In order to determine the most economical type of on-purpose PDH process, a complete analysis of all five technologies should be conducted.
The proposed plant will be located in Middle East and will produce 700 kilotons of propene a year. This location was chosen to supply the propene needs in the Middle East and Europe (ICIS, 2016). The project will be able to avoid the current supply glut of propene in China by focusing on supplying these markets. This location will also minimize propane costs because propane feed stocks are readily available from the oil refinery operations there.
Objective-time Chart

Project Name: Propane Dehydrogenation by Autothermal Reforming

Project Champions: Mr. John Wismer, Dr. Raymond Gorte, Dr. Leonard Fabiano

Project Leaders: Jeff Barsamian, Jayant Rao, Patrick Staiber, Eric Wamakima

Specific Goals: Evaluate the potential of an on-purpose propene plant with a capacity of 500kT/year using propane oxydehydrogenation and hybrid membrane separation

Project Scope:

- Design of oxydehydrogenation reactor complex
- Design of gas separation unit
- Design of hybrid membrane separation to achieve polymer grade 99.5% wt. purity
- Market and profitability analysis
- Determination of plant location

Out of scope:
- Distribution of final propene product

Deliverables:

- Business Opportunity Assessment
  - What is the market for propene?
  - What competitors currently produce propene?
- Manufacturing Capability Assessment:
  - Can the plant be built with reasonable capital investment?

Timeline: Complete design and economic analysis by April 12, 2016
Market and Competitive Analysis

Propene Uses

Propene is available in three grades of various purities: refinery grade (60-70%), chemical grade (93-94%), and polymer grade (minimum of 99.5%). The most common use of propene is polypropylene, which accounts for almost two thirds of global propene consumption. Polypropylene is one of the most versatile bulk polymers because of its excellent mechanical and chemical properties and has found uses in a variety of consumer and industrial products. Polypropylene and polypropylene alloys account for a third of the plastics used in the automobile sector. Injection molded polypropylene is used in electrical appliances, household goods, and toys. Film grade polypropylene is used in packaging, and polypropylene can be extruded into pipes, wire and cable. Although polypropylene experienced high levels of growth in the 1990s but has since dropped to around 5% a year due to the increased price of propylene compared to other base chemicals (ICIS, 2010).

Propene is also used in acrylonitrile, which is used to make acrylic fibers. Acrylic fibers have a variety of applications, from clothing to home furnishings. The third largest use of propene is for propylene oxide, and intermediate for the production of flexible foams and propylene glycol ethers. Other uses of propene include various alcohols, cumene, and acrylic acid.

Propene Market Overview

In the long term, reduction in propene supplies from steam crackers and refineries together with the resulting higher price levels are supporting investments in on-purpose production (IHS, 2016). In the short term, however, the market price for propylene is heavily influenced by the current global oversupply due to improved production and softer demand (ICIS
This oversupply is expected to persist and continue to affect the price of propene and its derivatives. US propene prices are expected to slowly climb in the first quarter as the supply of the preferred US cracker feedstock is varied (ethane vs. propane) (ICIS, 2016). American refinery propene production is also expected to remain strong due to strong operating rates as a result of low gasoline prices (ICIS, 2016).

Supply in Northeast Asia is also expected to increase in Q1 2016 due to additionally capacity from SK Advanced’s 600kT/year propane dehydrogenation unit expected to come on stream in March in South Korea (ICIS 2016). In China, propene consumption is expected to grow by 3.1 MT to 24.1 MT/year (Xiao, 2016). China already has 4 PDH plants with a total capacity of 2.1 million tonnes, with 2 more plants coming on this year (Xiao, 2016). Industry sources have said that Chinese PDH units have ben running at reduced capacity to prevent an oversupply of propene and “are expected to run around 70% of capacity this year in view of the projected demand for propylene” (Xiao, 2016). In Southeast Asia, IRPC is expected to run their 320 kT/year direct catalytic cracker on spec in Q1 (ICIS, 2016).

**Propene Competition**

A major source of propene is naphtha cracking and refinery cracking producing other products. However, the combination of reduced gasoline demand and the shift to lighter steam cracker feedstocks with lower propene yields has increased the amount of propene that is produced on purpose (Intratec, 2012). Current on purpose technologies include olefin metathesis, propane dehydrogenation, and methanol-to-olefins/methanol-to-propene, and fluid catalytic cracking (FCC). Olefin metathesis is a reversible reaction between ethylene and butenes in which double bonds are broken and then reformed to form propene (Intratec B, 2012). This process results in a 90 wt.% propane yield. Methanol-to-olefins/methanol-to-propene converts synthesis
gas to methanol and then converts the methanol to ethylene and propene. However, a large amount of methanol is required to make world scale propene plant. High severity FCC uses traditional FCC technology under severe conditions but only achieves conversions of around 25%.

There are five licensed technologies for propane dehydrogenation: CATOFIN from Lummus Technology, Oleflex from UOP, Fluidized Bed Dehydrogenation from Snamprogetti, STAR process from Thyssen Krupp Udhe, and PDH from Linde/BASF. The main differences between these technologies are the type of catalyst, regeneration methods, reactor design, and methods used to increase conversion. According to Inratec, there were at least 16 PDH units in operation with a capacity of 5260 kT/year of propene. Plans for 13 additional PDH units have been announced to increase capacity to 12,590 kT/year by the end of 2015 (Inratec). For the most part, most new units are based on the UOP technology (Gorte, 2016). If built now, our project would clearly be entering the market amidst a supply glut and tough economic conditions for propene producers. Producers are currently producing below capacity to avoid flooding the market.

Propane Market Overview

According to IFC International, “propane production is expected to continue to grow rapidly, keeping downward pressure on average propane prices relative to oil prices” (IFC, 2016). This is a positive sign for propene producers. If propane prices remain low, and propene prices rise to levels seen in 2014, this combination could allow for this project to make economic sense.
Figure 1 Process synthesis tree diagram showing developed decisions with rectangles and undeveloped decisions with diamonds
Figure 2 shows an overall block diagram with the process steps for converting propane to propene. The first step is the reaction of propane to propene. Depending on the reaction process there could be a number of different products. No matter which reaction process is used there will be a need for separating propane and propene from hydrogen or carbon dioxide. Because full conversion of propane is impractical, the final step in the process will have to separate propane from the desired product.

Reactors

The dehydrogenation of propane is facilitated by a number of catalysts. The catalyst can be based on chromium, nickel, or platinum. Chromium and nickel are significantly cheaper than platinum, but can only achieve molar propane conversions of about 10% while platinum catalysts have demonstrated conversions of up to 50% under certain conditions (Heraville, 2012). The significant recycle volume associated with the low conversion of propane would require increased reactor and separation capital that made platinum the metal of choice. Patent US20030139637 and the STAR Process by UHDE have reported propane conversions of 50% using 0.2-0.6% platinum on a hydrotalcite support (ThyssenKrupp, 2014).

Propane can be converted to propylene through standard dehydrogenation in which propane is fed through a catalyst bed with an inert carrier or oxydehydrogenation in which oxygen is also fed to the reactor to consume hydrogen and push the conversion of propane further. In
standard propane dehydrogenation platinum catalyst can reach propane conversions of about 20-30% and propylene selectivities up to 100% at temperatures above 550 °C. This reaction is endothermic and requires heating to maintain reactor temperatures and achieve the desired conversion. In oxydehydrogenation propane can be reached at conversions of 50% and the overall reaction is exothermic; depending on oxygen feeds the reactor may not need heating or cooling. Oxydehydrogenation also has side combustion reactions of propane and propylene with selectivities of about 3% (Rytter, 2003). Because of the large wide flammable limits of hydrogen, the concentration of oxygen to hydrogen has to be kept below 25% or above 96% by volume. Patent US20030139637 operates in the fuel lean regime which requires a large volume of gas heating and separations, but combusts all the hydrogen produced which removes the necessity of hydrogen separations and provides a large amount of heating for the reaction. The STAR Process operates in the fuel rich regime which does not consume all the hydrogen, but provides enough heat for the reaction. The STAR Process was chosen in favor of easier temperature control and avoiding increased capital costs to handle the larger volume of gases used by Patent US20030139637.

The catalyst has to be regenerated periodically due to deactivation from carbon deposition. In order for downstream operations to operate continuously the regeneration time has to be covered with excess reactor capacity and either storage or even more reactor capacity. The storage required decreases with increasing number of reactors, but fixed costs associated with the reactors and operational hazard increases with running more reactors. The excess reactor capacity required without storage also decreases with increasing number of reactors, but faces the same issues with increasing the number of reactors. Using 4 to 6 reactors as an optimum range of reactors, the capital required to store product is less expensive than increasing reactor capacity and dead time to forgo
storage. However, running reactors with excess capacity to avoid storage was chosen to avoid the safety risk associated with storing a large amount of gaseous fuel.

C3 Gas Separation from Lights

Once the choice of reactor was settled upon, oxydehydrogenation reactors, gas components to be separated out are water, carbon dioxide, carbon monoxide, hydrogen and lighter hydrocarbon components (lights). The water separation process is the first step because excess steam is fed to the reactor to decrease the vapor pressure of propane therefore water is removed first to decrease the overall size for the plant streams. The water is removed by simply cooling with cooling water and an adsorption column with 3A molecular sieves. The cooling water removes most of the water and the molecular sieve dries the gas by removing 95% of water present in the feed to the adsorption column.

Carbon dioxide is then removed next and various capture systems were considered. The systems considered were sodium carbonate, calcium carbonate and monoethanolamine (MEA) capture systems. The system decided upon was the MEA system because this capture system is purchased with its own utility provision system which saves on total utility cost for the process. The costing for the MEA system was estimated using the technoeconomic feasibility study performed on three different MEA capture systems with utilities. The process with the least utility cost and capital investment cost was decided upon (Hwang, 2012). The capture efficiency of the system is 94%.

Finally, prior to propane and propene separation, the other gas components are separated out. The options considered were a coldbox-pressure swing adsorption (PSA) system, cryogenic distillation, PRISM membrane separation. The coldbox-PSA system has the advantage of separating out hydrogen which could be sold as a byproduct. The hydrogen however is preferably
burnt as fuel to provide heating necessary for the process therefore does not require to be extracted using PSA. This separation is done by cryogenic distillation which separates out methane, ethane, ethene, hydrogen, carbon monoxide. This stream contents are burnt to provide heating as previously mentioned. The PRISM membrane separation only separates 85% of hydrogen and due to the 99.5% purity requirement of propene this process was not pursued.

**Propane/Propene Separation**

As was previously stated, three methods of propane/propene separation were considered for this report: using only a distillation column, using only a membrane, and using a hybrid configuration including elements of both previously mentioned designs. It was suggested that a hybrid separation system is the most optimal method of separation when compared to using only a distillation column or only a membrane (Benali, 2010). For this reason, the hybrid system was taken as the base-case and explored in the most detail in this report. The other designs were also explored and have their results summarized and are compared with the hybrid system in terms of economic viability.

When considering a hybrid separation system, the first major challenge was to decide whether the distillation column or the membrane would be used for the initial separation of propene from propane. Correspondingly, the configuration of the hybrid system had to be considered. A cost analysis and optimization report by Benali found that the most cost-effective configuration of a propane-propene hybrid separation system involves a distillation column performing the initial separation. The distillate of the column then undergoes further separation by passing through the membrane. Because Benali found this configuration to be the most cost effective in terms of capital and operating costs when used for C3 separation, it was pursued further by the group and chosen
as our base design which would be compared to the distillation only and membrane only separation systems.

**Product Storage**

It was decided that for the transportation of the propene product, tanker rail cars or tank capable of being transported by a truck would be used. These tanks are designed to handle pressures of 249 to 319 psi and temperatures of 14 to 149 F. Because of this, the permeate of the membrane must be liquefied and cooled to temperatures within the range of the tanker’s specifications.
Assembly of Database

Aspen Simulation Specification

The overall process design was simulated in ASPEN Plus V8.8 software. The UNIQUAC property method which uses Ideal gas and Henry’s law was used for the simulation except for the adsorption, absorption and membrane separations which were modelled in excel and their results hard coded into aspen as separator blocks.

The reactors were modelled using the RSTOIC which is a stoichiometric reactor which fractional conversions for all major and side reactions are specified. This model was used for the reformer and the oxyreactor. The distillation columns were initially modelled with DSTWU which provided insight on parameters such as minimum reflux ratio, feed tray location and distillate rate. The more rigorous model RADFRAC was then used with the known parameters in the final process design. The column parameters were then manipulated to produce desired results of separation using design specs.

The membrane separation process as mentioned before were modelled as simple separators where the component fraction in the permeate and retentate streams were manually entered. Similar process was applied to the adsorption and absorption processes. To simulate pressure drop across the membrane, turbines were placed on the permeate streams. Finally, for heat exchangers HEATER and HEATX models were applied.

Input Costs

The main utility inputs in the process are natural gas, electricity, cryogenic refrigeration, steam at various pressures, nitrogen gas as an inert, cooling and chilled water. The costs of these inputs were obtained from Process Design Principles, 3rd edition, by Seider, Seider, Levin and Windago.
The utility cost for the carbon dioxide capture system were scaled from technoeconomic feasibility study of capture systems (Hwang, 2012).

Raw material inputs for the continuous process are propane and oxygen. The price of propene was estimated by incorporating the price difference between propane and propene provided by our faculty advisor Dr. Raymond Gorte. The price of oxygen was estimated from oxygen production systems providing oxygen purity of 97% (Wilcox, 2005).

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<th>Material</th>
<th>Ratio (lb per lb propene)</th>
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<td>Oxygen</td>
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<td>Propene</td>
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**Table 1 Summary of material costs for the process design**

Safety and MSDS

Safety measures are discussed in the other consideration section. The major safety issue is flammability of the hydrocarbon components in the process design. Material Safety Data Sheets are compiled in Appendix C which further outline safety conditions.
Process Flow Diagram and Material Balances

Process Flow Diagrams

Figure 3 Schematic of reactor complex blocks and streams
Figure 4: Schematic of gas separation

Water Removal

Carbon Dioxide Removal

Hydrogen and Lights Removal

**KEY:**
- S: Stream
- CW: Cold Water
- RP: Refrigeration
- T: Turbine
- F: Free Water Collector
- AD: Adsorption Column
- MX: Represents Streams Mixing
- AB: Absorption Column
- HX: Heat Exchanger
- P: Pump
- RB: Reboiler
- C: Compressor
- DC: Distillation Column
- RA: Reflux Accumulator
- CN: Condenser
Figure 5 schematic of C3 separations using a hybrid system
Figure 5 schematic of C3 separations using only membranes
Figure 6 schematic of C3 separations using only a distillation column
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Process Description

The overall process was split into three sections: steam production, propane dehydrogenation, initial gas separation, and the final gas separation of propane and propene.

Propane Dehydrogenation

Water is fed to the boiler H-101 as shown in Figure 3 along with recycled water from downstream processes at 166 °F to produce 385471 lb/hr of steam at 73 psi. The steam is mixed with the reactor feed in a 2:1 molar ratio of steam to propane to keep the partial pressure of propane low and prevent carbon deposition on the catalyst which extends the length of time the catalyst can be used in reaction before regeneration. The steam is heated to a temperature of 467 °F to ensure that the vapor fraction of the reactor feed mixture remains at 1 after mixing with the propane feed. The heat duty on the boiler is 438 MMBTU/hr. Recycled hydrogen and propane are burned to supply the boiler with 383 MMBTU/hr of heat and the balance is covered with natural gas. The feed mixture is then sent through a heat exchanger with the reactor products to raise the feed mixture to reactor temperatures of 1094 °F.

After the propane feed and recycle have been mixed with steam and raised to reactor temperatures, the feed mixture is split into three equal streams and sent to the three reformers in operation. The propane reacts in the packed bed of 0.2-0.6% Pt-Sn/ZnAl₂O₅ catalyst at a temperature of 1094 °F and pressure of 73 psi. The feed has a residence time of 2 seconds and achieves 30% molar conversion of propane. Propane reacts according to the following reactions:

\[
C_3H_8 \rightarrow C_3H_6 + H_2 \quad (1)
\]

\[
C_3H_8 \rightarrow C_2H_4 + CH_4 \quad (2)
\]

\[
C_3H_8 + H_2 \rightarrow C_2H_6 + CH_4 \quad (3)
\]
After a reactor runs for six hours it is allotted an hour for shutdown and startup and an hour for catalyst regeneration. The catalyst is regenerated by first flushing the catalyst bed with pure nitrogen from the air separation unit to remove any large concentrations of fuel, and then air is fed through the catalyst bed at 1094 °F to burn off carbon deposition on the catalyst. With 4 reactors the 2-hour dead time is shifted from one reactor to the next to maintain a continuous operation of 3 reactors at any time.

Following the reformers, the products are fed to another reactor packed with the same catalyst that co feeds pure oxygen to react with hydrogen product from the reformer reactors and push the propane conversion. Some of the hydrocarbons in the oxydehydrogenation reactors react with oxygen to form carbon monoxide and carbon dioxide side products. The following reactions occur in the oxydehydrogenation of propane:

\[
C_3H_8 + 2H_2 \rightarrow 3CH_4 \quad (4)
\]

\[
CH_4 \rightarrow C + 2H_2 \quad (5)
\]

\[
C_3H_8 + \frac{1}{2}O_2 \rightarrow C_3H_6 + H_2O \quad (6)
\]

\[
C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \quad (7)
\]

\[
C_3H_6 + \frac{9}{2}O_2 \rightarrow 3CO_2 + 3H_2O \quad (8)
\]

\[
CH_4 \rightarrow C + 2H_2 \quad (9)
\]

\[
2CO \rightarrow C + CO_2 \quad (10)
\]

\[
C + \frac{1}{2}O_2 \rightarrow CO \quad (11)
\]

\[
C + H_2O \rightarrow CO + H_2
\]

\[
C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2
\]
Propylene has a lower selectivity in the oxydehydrogenation reactors of 88% with a CO₃ selectivity 10% and a small amount of light ends forming. The oxydehydrogenation produces carbon dioxide, which must be removed using MEA absorption later in the process, and carbon monoxide, which can be separated from propylene along with hydrogen. Even with the formation of these side products, oxydehydrogenation is favorable because consumption of hydrogen and increased conversion of propylene lower the separation duties of the hydrogen and the C3 separation columns. The oxydehydrogenation reactor operates adiabatically and the overall reaction system is exothermic causing the product stream to heat to about 1211 °F. This heat increase reduces the selectivity of propylene, but the increase in temperature offers a driving force for the reactor feed to increase to reformer temperatures during the product heat recovery.

C3 Gas Separation from Lights

This section is represented by Section 200 in Figure 2. Figure 4 provides more detail on the equipment for the C3 gas separation from lights section. The reactor effluent goes through turbine T-201 to reduce the pressure of the reactor effluent from 52.5 psi to 34.8 psi which is the required pressure for the adsorption column. The temperature decreases from 461 F to 419 F. The turbine produces recoverable power that is used in running compressors. After expansion the gas is cooled further using cooling water heat exchanger HX-201 cooling the reactor effluent from 419 F to 176 F. In this heat exchanger water precipitates out 97.3% of the water present in the reactor effluent. To save on utilities cost this water is recycled to the steam reformer. The cooler stream at lower pressure then goes through an adsorption column with 3A molecular sieves. The adsorption column separates out 95% of the remaining water. The water adsorption column goes through regeneration every 8hrs. The regeneration process begins with taking one of the adsorption columns offline after 80% loading of the 3A molecular sieves. Once loaded the other regenerated
column goes online. The regeneration process begins with 0.5 hours of nitrogen purging to remove any residual hydrocarbons in the column then hot air at 350 F to remove the loaded water for 6.5 hours. The column is then allowed to cool for 1 hour before being brought back online.

After water removal, carbon dioxide is removed from the reactor effluent. The monoethanolamine capture system has an efficiency of 94% (Hwang, 2012). The capture system is represented by AB-201 with the accompanied representative equipment shown in Figure 4. The gas steam then goes through a series compressive steps to increase the pressure from 25 psi to 300 psi for the cryogenic distillation. C-201 and C-202 achieve this pressure change. This pressure change is associated with a 176 F to 423 F. DC-202 separates out hydrogen, methane, ethane, ethane and the remaining carbon dioxide. The refrigeration cost of the column are high because cryogenic temperatures are necessary to separate out hydrogen. The separated out hydrogen is combusted in various heaters to provide necessary heating. The distillation column has 4 passes to reduce the diameter of the column and reduce cost.

Perfectly selective Pt-Sn Based Catalyst

During the design process information about the selectivity of a similar catalyst being 100% selective for the production of propene was introduced (Gorte, 2016). This would mean that gas separation of methane, ethane, ethane, carbon dioxide and carbon dioxide would be unnecessary. This would result in savings in the capital costs for the MEA capture system as well as the utilities for it. While there would be savings in not requiring the carbon dioxide capture system, cryogenic distillation would still be necessary for the removal of hydrogen from the hydrocarbon stream. The source also claims a lower conversion of 35% which would require overall greater recycle stream. The effect of lower selectivity would have to be investigated but one of the sure effects would be more energy intensive hydrogen separation due to the larger recycle stream. The removal of these
separation requirements could save money depending on how much cryogenic separation of hydrogen costs increase due to the reduction in single pass conversion.

**Propane/Propene Separation**

**Hybrid System**

The bottoms products from the hydrogen separation column is separated further, with the end goal to produce 99.5% pure, polymer grade propene which can then be sold. To do this, a hybrid separation process, which can be seen in Figure 4, is used which takes advantage of both multi-stage distillation columns and membranes to separate propene from the hydrocarbon mixture.

The bottoms product from the hydrogen separation column, DC-202, is comprised of 47.5% propene by mass. The desired product has a 99.5% propene composition. To achieve this, a distillation column and membrane are used in series. The distillation column, DC-500, produces a 68.4% propene by mass distillate at a temperature and pressure of 103 F and 225 psi respectively. Because of the expected size of the distillation column, 4 passes are used to limit the diameter of the column and consequently the cost. The temperature and pressure of this liquid distillate must be increased so that the stream is fed to the membrane as a vapor at a high enough pressure to account for the pressure drop through the membrane. The pressure of the liquid stream is increased to 575 psi using centrifugal pump, P-502. Heat exchanger, HX-500, increases the temperature of the stream to 162 F using heat from the final product stream. To vaporize the stream, heater H-500 is used to raise the temperature from 162 F to 257 F.

The high pressure, gas stream is then passed through membrane M-500. The membrane provides further purification of the stream, separating propene from the inlet stream. Propene passes through the membrane and exits in the permeate stream at a concentration of 99.5 percent. This product stream is at a temperature of 94 F and pressure of 20 psi. For transportation of the
propene product, it is desired that the stream be liquefied and stored at 100 F and 250 psi. To do this, compressor C-500 is used to increase the stream’s pressure from 20 to 250 psi. The exit temperature of the compressor is 338 F. Because the desired temperature is 100 F, the product stream exchanges some heat with the membrane’s feed stream in heat exchanger H-500. The exit product stream temperature is 113 F. To achieve the desired 100 F, cooling water is used in heat exchanger H-501. The product stream is now at the desired composition, temperature, and pressure and can be safely stored and transported.

The bottoms product of the distillation column, DC-500, and the retentate of the membrane, M-500, can be collected and recycled to the reactor. The valve, V-500, decreases the pressure of the bottoms stream to 20 psi so that the bottoms and retentate streams are at the same pressure for mixing. After the liquid bottoms and vapor retentate are mixed using mixer MX-500 the stream is split using splitter, SP-500, with 90% of the stream being recycled and the other 10% being purged and burned for heat. The 90% that is being recycled is heated from -29 F to 77 F using low pressure steam in heater H-502 to ensure the stream is entirely vapor. Compressor C-501 is then used to increase the pressure of the stream from 20 to 73 psi so that it can be mixed with the feed propane at identical pressures.

**Distillation Column**

The bottoms products from the hydrogen separation column is separated further, with the end goal to produce 99.5% pure, polymer grade propene which can then be sold. To do this, a multi-stage distillation column, which can be seen in Figure 6, is used to separate propene from the hydrocarbon mixture.

The bottoms product from the hydrogen separation column, DC-202, is comprised of 47.5% propene by mass. The desired product has a 99.5% propene composition. To achieve this, the bottoms product is fed to a distillation column. The distillation column, DC-300, produces a
99.5% propene by mass distillate at a temperature and pressure of 99 F and 225 psi respectively. Because of the expected size of the distillation column, 4 passes are used to limit the diameter of the column and consequently the cost.

The bottoms product of the distillation column, DC-300, is collected and recycled to the reactor. The stream is split using splitter, SP-500, with 90% of the stream being recycled and the other 10% being purged and burned for heat. The pressure of the 90% that is being recycled is decreased from 245 to 73 psi using the valve, V-300, so that it can be mixed with the feed propane at identical pressures.

Membrane System

The bottoms products from the hydrogen separation column is separated further, with the end goal to produce 99.5% pure, polymer grade propene which can then be sold. To do this, two membranes are used in series to separate propene from the hydrocarbon mixture, with the process being depicted in Figure 5.

The bottoms product from the hydrogen separation column, DC-202, is comprised of 47.5% propene by mass. The desired product has a 99.5% propene composition. To achieve this, the bottoms product is first fed to heater, H-400, which raises the stream temperature to 160 F and vaporizes the stream. The high pressure, gas stream is then passed through membrane M-400. This membrane provides an initial purification of the stream, separating propene from the inlet stream. Propene passes through the membrane and exits in the permeate stream at a concentration of 98.5 percent. This product stream is at a temperature of 3 F and pressure of 20 psi.

Before being fed to the second membrane, the pressure of the stream is increased to 290 psi using compressor, C-400, which also increases the temperature of the stream to 250 F. The stream is then fed through membrane M-401, which provides a final separation of propene from
propane. Propene passes through the membrane and exits in the permeate stream at a concentration of 99.5 percent. This product stream is at a temperature of 150 F and pressure of 20 psi.

For transportation of the propene product, it is desired that the stream be liquefied and stored at 100F and 250 psi. To do this, compressor C-500 is used to increase the stream’s pressure from 20 to 250 psi. The exit temperature of the compressor is 403 F. Because the desired temperature is 100 F, cooling water is used in heat exchanger H-401. The product stream is now at the desired composition, temperature, and pressure and can be safely stored and transported.

The retentate of membranes, M-400 and M-401, can be collected and recycled to the reactor. After both vapor retentate streams are mixed using mixer MX-400, the stream is split using splitter SP-400 with 90% of the stream being recycled and the other 10% being purged and burned for heat. The pressure of the 90% that is being recycled is increased from 20 to 73 psi using compressor C-402 so that it can be mixed with the feed propane at identical pressures.
Energy Balance and Utility Requirements

To maximize efficiency, all streams were evaluated for their potential to heat or cool another process. In particular, the remaining H₂ that was removed (S-210, Figure 4) and the purge stream (S-516, Figure 5) have a significant amount of heat (7.88E8 BTU/hr) and are combusted to provide heat to other units in the process.

H₂ that is generated through the dehydrogenation process is reacted exothermically with the oxygen in the oxyreactors (R-102, R-104, R-106, R-108, Figure 3) to produce water. Since the oxyreactor is run adiabatically at 1094F, the reactor requires no utilities and heats the effluent streams (S-133 and associated streams, Figure 3) to 1211F. This increased temperature allows heat exchanger HX-101 to have a greater driving potential and thus drive more heat into the reformer feed stream (S-103).

R-101 and associated reactors run at 1094F and have an energy requirement of 4.05E7 BTU/hr each. This energy is supplied by the combustion of S-210. The steam fed to our reactor is recycled from our water adsorption unit in S-212 and boiled in H-101. The energy requirement of the fired heaters H-101, H-500 and H-502 is satisfied fully by the recovered energy from the streams S-210 and S-516. The distillation columns DC-202 and DC-500 heating requirement in the reboilers was also met by the combustion of S-210 and S-516 in fired heaters. The streams S-210 and S-516 provide a total of 7.88*10⁸ BTU/hr which as mentioned before covers most of the heating requirements for the process.

Compression of the gas prior to cryogenic distillation is the most electrical power intensive and requires a total of 1.67*10⁴ kW. This is necessary to reduce the temperature at which cryogenic distillation occurs. The compressors and pumps in the process are C-201, C-202, C-500, C-501 and P-500. In the process however power is generated through gas expansion
in the turbine T-201 which produces 5421 kW. This power is integrated into the process and used to run the compressors. Another electricity requirement is in running the blower whose power rating is 46.2 kW. The total electricity use for the process design $1.77 \times 10^6$ kW/year.

Cryogenic distillation, DC-202 is the most energy intensive process requiring a total of 1.63 GJ/year of refrigeration. The refrigeration system is an ethylene based system providing refrigeration at -150°F. The top of the column is maintained at -96°F which is necessary for the separation of hydrogen.

The MEA capture system, AB-201 is accompanied with its own utility system which is overall cheaper than purchasing individual heating and cooling requirements. The capture system therefore only has the dollar amount necessary to run it and not the individual utilities which are provided in literature (Hwang, 2012).

The reactors (R-101 – R-108) and adsorption column AD-201 require a nitrogen purge during the regeneration cycles to purge out any hydrocarbons before the units are regenerated. The total nitrogen requirement is estimated to be about $4.27 \times 10^6$ CF/year. It is highly likely that this number is an under estimate because the duration of the purging is likely to be longer than previously stated.

Other cooling requirements of the process are satisfied using cooling water and chilled water. The units H-201, DC-500 and H-501 require cooling water. The cooling water is purchased at 80°F and has an expected increase in temperature to 120°F Seider et, al. The total amount of cooling water necessary in the process is $4.12 \times 10^{10}$ gal/year. The chilled water is necessary in the adsorption column to provide dry air for the regeneration of the adsorption column. The chilled air is purchased at 40°F and has an expected increase in temperature to 55°F Seider et, al. The total cooling water energy necessary for the process is $2.68 \times 10^5$ GJ/year.
HX-101 reduces the temperature of the oxyreactor effluent S-113 from 1211F to S-201’s temperature of 461F. At the same time, the feed to the reformers is increased from 288F to 1094F, which is the operating temperature of reformer R-101 and associated reformers. The heat duty of HX-101 is 3.9E8 BTU/hr.

HX-101 reduces the temperature of the oxyreactor effluent S-113 from 1211F to S-201’s temperature of 461F. At the same time, the feed to the reformers is increased from 288F to 1094F, which is the operating temperature of reformer R-101 and associated reformers. The heat duty of HX-101 is 3.9E8 BTU/hr.

HX-201 is the first exchanger in the process involving cooling water. This exchanger serves to cool the reactor effluent prior to separation processes in AD-201 and AB-201 as much as possible using cooling water. The hot stream (S-202), with a flow rate of 866,281 lb/hr is cooled from 419 F to 176 F. The duty of the exchanger is 550MM BTU/hr.

HX-301 reduces the temperature of final product stream by heating the feed stream to the membrane by cooling the final product stream. The heat duty of HX-101 is 1*10^6 BTU/hr.

The amounts and costs of the utilities required for this process are summarized in the Table 2 and 3 below.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Unit</th>
<th>Ratio (per lb of propene)</th>
<th>Utility Cost ($ per unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>MMBTU</td>
<td>0.000381404</td>
<td>1.78</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>0.110229795</td>
<td>0.07</td>
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<tr>
<td>Refrigeration (-150F)</td>
<td>GJ</td>
<td>0.001057012</td>
<td>33.2</td>
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<tr>
<td>MEA Capture System</td>
<td></td>
<td>6.47969E-10</td>
<td>1330000</td>
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<tr>
<td>Nitrogen</td>
<td>CF</td>
<td>0.002767269</td>
<td>0.0782</td>
</tr>
<tr>
<td>Cooling Water</td>
<td>gal</td>
<td>26.72223232</td>
<td>0.0001</td>
</tr>
<tr>
<td>Chilled Water</td>
<td>GJ</td>
<td>0.000173656</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total Weighted Average Utility Cost</strong></td>
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<td></td>
<td><strong>$0.048/lb propene</strong></td>
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</tbody>
</table>
Table 3: Detailed Utility Requirements for all units

<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (MMBTU/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>H-101</td>
<td>2.62E+06</td>
</tr>
<tr>
<td>Natural gas</td>
<td>R-101</td>
<td>3.55E+05</td>
</tr>
<tr>
<td>Natural gas</td>
<td>R-103</td>
<td>3.55E+05</td>
</tr>
<tr>
<td>Natural gas</td>
<td>R-105</td>
<td>3.55E+05</td>
</tr>
<tr>
<td>Natural gas</td>
<td>R-107</td>
<td>3.55E+05</td>
</tr>
<tr>
<td>Natural gas</td>
<td>H-500</td>
<td>4.76E+05</td>
</tr>
<tr>
<td>Natural gas</td>
<td>DC-202</td>
<td>4.82E+05</td>
</tr>
<tr>
<td>Natural gas</td>
<td>DC-500</td>
<td>1.93E+06</td>
</tr>
<tr>
<td>Natural gas</td>
<td>H-502</td>
<td>9.20E+04</td>
</tr>
<tr>
<td>Natural gas</td>
<td>H-500</td>
<td>4.76E+05</td>
</tr>
<tr>
<td>Natural gas- recovered energy</td>
<td>S-210, S-516</td>
<td>-6.90E+06</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>5.89E+05</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (kWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>C-201</td>
<td>6.55E+07</td>
</tr>
<tr>
<td>Electricity</td>
<td>C-202</td>
<td>8.04E+07</td>
</tr>
<tr>
<td>Electricity- recovered energy</td>
<td>T-201</td>
<td>-5.42E+07</td>
</tr>
<tr>
<td>Electricity</td>
<td>AD-201</td>
<td>4.05E+05</td>
</tr>
<tr>
<td>Electricity</td>
<td>P-500</td>
<td>2.01E+06</td>
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<tr>
<td>Electricity</td>
<td>DC-500</td>
<td>2.91E+06</td>
</tr>
<tr>
<td>Electricity</td>
<td>C-500</td>
<td>4.84E+07</td>
</tr>
<tr>
<td>Electricity</td>
<td>C-501</td>
<td>2.47E+07</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1.70E+08</strong></td>
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<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (GJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigeration -150F</td>
<td>DC-202</td>
<td>1.63E+06</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1.63E+06</strong></td>
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<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA Capture System</td>
<td>AD-202</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1</strong></td>
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<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (CF/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen Purge</td>
<td>AD-201</td>
<td>4.27E+06</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>4.27E+06</strong></td>
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<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (MMBTU/yr)</th>
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</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>AD-201</td>
<td>1.54E+04</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1.54E+04</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (gal/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Water</td>
<td>H-201</td>
<td>2.80E+10</td>
</tr>
<tr>
<td></td>
<td>DC-500</td>
<td>1.20E+10</td>
</tr>
<tr>
<td></td>
<td>H-501</td>
<td>1.30E+09</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>4.12E+10</strong></td>
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<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (GJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilled Water</td>
<td>AD-201</td>
<td>2.68E+05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>2.68E+05</strong></td>
</tr>
</tbody>
</table>
Equipment List and Unit Descriptions

Distillation Columns and Associated Equipment

DC-202 is a multistage distillation column that chiefly separates hydrogen, methane, ethane, ethane and carbon monoxide from propane and propene prior to hybrid separation. It contains 20 stages and fed (S-208) at the lowest tray, stage 19. The feed has a flow rate of 418,458 lb/hr. The molar reflux ratio of the column is 4.5. The condenser of the column operates at 270 psi with a 10 psi condenser pressure drop and 0.11 pressure drop for each stage. The distillation column bottoms S-501, a propane and propene rich stream flows at 406,818 lb/hr with conditions of 125 F and 282 psi. The distillation column overhead S-210, a lights rich stream flows at 11,640 lb/hr with conditions of -96 F and 270 psi. The height and diameter of the column were 48 ft and 23.1 ft, respectively. The total bare module cost of the column was $9.5 million with an estimated $57 million in utilities cost per year.

P-203 is a cast iron, centrifugal pump that is used to increase the pressure in the condenser. Designed to accommodate a flow rate of 34,403 gallons per minute and a head of 334.4 ft, the pump’s bare module cost is $256,000. The pump requires 1496 kW of electricity which is a yearly utility cost of $917,000.

P-205 is a cast iron, centrifugal pump that is used to increase the pressure in the reboiler. Designed to accommodate a flow rate of 1,800 gallons per minute and a head of 493 ft, the pump’s bare module cost is $82,000. The pump requires 78.3 kW of electricity which is a yearly utility cost of $48,000.

RA-202 is a reflux accumulator used in DC-500. The accumulator is a 45,990 ft³ horizontal, carbon steel tank. The accumulator has a length of 61.6 feet and diameter of 30.8 feet.
and is assumed to have a residence time of 5 minutes. The reflux accumulator’s bare module cost is $295,000.

CN-202 is the condenser associated with the distillation column, DC-500. The condenser operates at 270 psi so that vapor from the top stage of the distillation column, DC-500, can be cooled using cooling water. CN-500 is made of carbon steel and has a length of 20 ft. With a duty of 146.12 MMBTU, the condenser has a surface area of 17,795 ft². This leads to an operating cost of $54,158,000 a year using cooling water and a bare module cost of $1,200,000.

RB-202 is the reboiler associated with the distillation column, DC-500. The reboiler is made of carbon steel and has a length of 20 ft. With a duty of 44.5 MMBTU, the reboiler has a surface area of 3,712 ft². The bare module cost of the reboiler is $2,100,000.

The multistage distillation column, DC-500, is used to provide an initial separation of propene from propane. It was found for propane-propene separation, that 90 was the most effective number of stages to be used in a distillation column (Benali, 2010). Trays in the column were spaced two feet apart. Because the materials being distilled offer no corrosive or reaction based concerns, carbon steel could be used as the construction material. The feed stream, S-501, enters the distillation column at the 45th tray at a temperature of 125 F and pressure of 282 psi. This feed stream is 47.5% propene by mass and has a flow rate of 407,700 lb/hr. To obtain an acceptable separation of propene while keeping costs to a minimum, a reflux ratio of 5 was used. The condenser of the column operates at 225 psi with a 10 psi condenser pressure drop and 0.11 pressure drop for each stage. The bottoms product, S-503, has a flow rate of 125,300 lb/hr with the conditions of 121 F and 245 psi and is only .4% propene by mass. The column’s distillate, S-502, is 68.4% propene by mass flowing at 282,400 lb/hr and is obtained at 103 F and 225 psi.
The final height of the column is 192 feet with a diameter of 29.9 feet. This results in a purchase cost of $10,875,000 and a bare module cost of $45,240,000.

P-500 is a cast iron, centrifugal pump that is used to increase the pressure in the condenser. Designed to accommodate a flow rate of 7,100 gallons per minute and a head of 337 ft, the pump’s bare module cost is $79,600. The pump requires 308 kW of electricity which is a yearly utility cost of $189,000.

P-501 is a cast iron, centrifugal pump that is used to increase the pressure in the reboiler. Designed to accommodate a flow rate of 555 gallons per minute and a head of 493 ft, the pump’s bare module cost is $18,900. The pump requires 24 kW of electricity which is a yearly utility cost of $14,800.

RA-500 is a reflux accumulator used in DC-500. The accumulator is a 9,470 ft³ horizontal, carbon steel tank. The accumulator has a length of 36 feet and diameter of 18 feet and is assumed to have a residence time of 5 minutes. The reflux accumulator’s bare module cost is $1,172,000.

CN-500 is the condenser associated with the distillation column, DC-500. The condenser operates at 225 psi so that vapor from the top stage of the distillation column, DC-500, can be cooled using cooling water. CN-500 is made of carbon steel and has a length of 20 ft. With a duty of 227 MMBTU, the condenser has a surface area of 27,600 ft². This leads to an operating cost of $1,196,000 a year using cooling water and a bare module cost of $1,066,000.

RB-500 is the reboiler associated with the distillation column, DC-500. The reboiler is made of carbon steel and has a length of 20 ft. With a duty of 220 MMBTU, the reboiler has a surface area of 18,400 ft². The bare module cost of the reboiler is $729,000.
**MEA Absorption Column**

AB-201 is an absorption column whose main purpose is to separate out carbon dioxide from the reactor effluent prior to propane and propene hybrid separation process. This is part of the system as mentioned will be purchased along with its own utility production system. The efficiency of the carbon dioxide separation is 94% of the carbon dioxide present in the feed stream is captured. The feed S-205 has a flowrate of 423,494 lb/hr with conditions 176F and 30 psi. The outlet stream conditions were assumed to be similar to the feed conditions with an allowable pressure drop of 5 psi through the column. The gas product stream therefore has a flowrate of 418,458 lb/hr and 176 F and 25 psi. The total bare module cost the capture system was estimated to be $3.17 million and operating costs of $1.3 million.

**Water Absorption Column**

AD-201 is an adsorption column which principally dries the reactor effluent stream prior to the gas separation process of propane and propene. The adsorption column dimensions are 35.7ft and 11.9ft in height and diameter respectively. The system requires two such columns a blower, chiller, heater, and heat exchanger. The packing for the column is 3A molecular sieves which allows the gas molecules other than water to pass through. The loading capacity of the column is 92% with a total cycle time of 8hrs. For the regeneration process hot air at 350 F is blown through for 7 hours and 1 hour allowed for transition and cooling of the packing. The total bare module cost of the system is $3.8 million with yearly utilities of $1.7 million.

**Compressors**

C-201 is a carbon steel electric motor drive centrifugal compressor. C-201 functions to compress the gas in S-206, prior to cryogenic distillation in DC-202. S-206 has a flow rate of
419,000 lb/hr and is at 176 F and 35 psi. The outlet stream S-207, comes out at 100 psi and 294 F. The compressor is isentropic and operates at 72% efficiency. A compressor rating of horsepower required is 10,030 hp. The compressor total bare module cost was estimated to be $7.1 million and $4.6 million in electricity utilities. The bare module cost incorporates intercooling costs for the compressor.

C-202 is a carbon steel electric motor drive centrifugal compressor. C-202 functions to compress the gas in S-207, prior to cryogenic distillation in DC-202. S-207 has a flow rate of 419,000 lb/hr and is at 294 F and 100 psi. The outlet stream S-208, comes out at 300 psi and 423 F. The compressor is isentropic and operates at 72% efficiency. A compressor rating of horsepower required is 12,000 hp. The compressor total bare module cost was estimated to be $8.5 million and $5.6 million in electricity utilities. The bare module cost incorporates intercooling costs for the compressor.

C-500 is a cast iron and stainless steel, centrifugal compressor that is used to increase the pressure of the product stream so that it can be liquefied and transported. The inlet stream, S-507, enters at 20 psi, 94 F, and a flow rate of 177,100 lb/hr. The outlet stream, S-508, has the same flow rate, an increased pressure of 250 psi, and a temperature of 338 F. The compressor requires 7410 HP and 5530 kW of electricity which is a yearly utility cost of $3,389,000. The compressor’s bare module cost is $5,251,000.

C-501 is a cast iron and stainless steel, centrifugal compressor that is used to increase the pressure of the recycle stream so that it can be transported and mixed with the propane feed stream, S-103. The inlet stream, S-514, enters at 20 psi, 77 F, and a flow rate of 207,500 lb/hr. The outlet stream, S-515, has the same flow rate, an increased pressure of 78 psi, and a
temperature of 181 °F. The compressor requires 3780 HP and 2820 kW of electricity which is a yearly utility cost of $1,727,000. The compressor’s bare module cost is $3,062,000.

Turbine

T-201 is a turbine whose main function is to lower the pressure of stream S-201, which is at a temperature and pressure of 461 °F and 52.5 psi respectively. This decrease in pressure is necessary for the functioning of the absorption and adsorption columns in the process. The output temperature and pressure of the turbine are 419 °F and 35 psi. The turbine operates at 72% isentropic efficiency produces net work of 8,349 hp. The bare module cost of the turbine is $1.4 million.

Pumps

P-502 is a cast iron, centrifugal pump that is used to increase the pressure of the stream being fed to the membrane. The inlet stream, S-502, enters at 225 psi and a flow rate of 282,400 lb/hr. The outlet stream, S-504, has the same flow rate and an increased pressure of 575 psi. Designed to accommodate a flow rate of 1180 gallons per minute, the pump’s bare module cost is $44,000. The pump requires 230 kW of electricity which is a yearly utility cost of $141,000.

Heat Exchangers

HX-101 is a shell and tube heat exchanger that recovers heat from the reactor products to heat the reactor feed. The reactor product is fed tube side at an inlet temperature 1211 °F at a flow rate of 824,000 lb/hr and released and an outlet temperature of 353°F. The reactor feed is fed shell side at an inlet temperature of 279 °F at a flow rate of 807,000 lb/hr and released at an outlet temperature of 1094 °F. The heat exchanger recovers 442 MMBTU/hr which requires a surface area of 21,000 square ft. The tubes are composed of stainless steel to handle the high reactor product temperature. The total bare module cost of the heat exchanger is $1,313,000.
HX-201 is the first exchanger in the process involving cooling water. This exchanger serves to cool the reactor effluent prior to separation processes in AD-201 and AB-201 as much as possible using cooling water. The hot stream (S-202), with a flow rate of 866,281 lb/hr is cooled from 419 F to 176 F. The duty of the exchanger is 550MM BTU/hr. This exchange is accomplished using five units with an area of 11,000 ft$^2$ each and the total bare module cost of $0.8 million. The cooling water utility for the system is $2.8 million per year.

The shell and tube heat exchanger heat exchanger, HX-500, is used to both increase the temperature of the stream fed to the membrane and to cool the product stream so that it can be transported. The cold inlet stream, S-504, enters at 106 F and a flow rate of 282,400 lb/hr and exits at the same flow rate at 162 F in stream S-505. The hot inlet stream, S-508, enters at 388 F and a flow rate of 177,100 lb/hr and exits at 113 F at the same flow rate, S-509. The heat duty is 17.55 MMBTU/hr which requires a surface area of 2,220 ft$^2$. The heat exchanger is made of carbon steel and has a bare module cost of $163,900.

**Heaters**

Heater H-101 is a steam boiler that produces high pressure steam to be fed with propane to the reactors to reduce coking of the catalyst which increases reactor run time. The boiler is fed 385,000 pounds of water per hour, most of which is recycled from downstream separations. The water is fed at 166 °F and boiled at a pressure of 73 psi and heated to a temperature of 467 °F. The duty on the boiler is 438 MMBTU/hr. Some of the boiler fuel cost is covered by recycled hydrogen, propane, and a small amount of propylene while the rest of the cost is covered by burning natural gas. The boiler is composed of stainless steel 304 and has a total bare module cost of $74,400,000.
The heater, H-500, is a fired heater that is used to vaporize the stream fed to the membrane. The cold inlet stream, S-505, enters at 162 °F and a flow rate of 282,400 lb/hr and exits at the same flow rate and 257 °F in stream S-506. The heater is made of carbon steel and has a bare module cost of $1,932,000. The heat duty is 54.33 MMBTU/hr and by burning recycled hydrogen, the utility cost is $847,000.

The heater, H-501, is used to liquefy the product stream so that it can be stored and transported. The hot inlet stream, S-509, enters at 113 °F and a flow rate of 177,100 lb/hr and exits at the same flow rate and 100 °F in stream S-510. The heat duty is 24.6 MMBTU/hr which requires a surface area of 2,470 ft². The heater is made of carbon steel and has a bare module cost of $177,800. Cooling water is used and the yearly utility cost is $129,500.

The heater, H-502, is a fired heater that is used to vaporize the recycle stream. The cold inlet stream, S-513, enters at -29 °F and a flow rate of 207,500 lb/hr and exits at the same flow rate and 71.6 °F in stream S-506. The heater is made of carbon steel and has a bare module cost of $727,000. The heat duty is 10.6 MMBTU/hr and by burning natural gas, the utility cost is $164,000.

Reactors

Reactors R-101, R-103, R-105, and R-107 are identical reactors that operate much like steam reformers. The function of the reactors is to continuously convert propane into propylene and hydrogen. 121,000 pounds of propylene are generated per hour by each reactor. Propane is fed with steam to the reactor at a temperature of 1094 °F and pressure of 73 psi. Steam is fed at a 2:1 steam to propane molar ratio to prevent coking of the catalyst and increase the activity of the catalyst before regeneration. Each reactor achieves a molar conversion of propane of 32% with a propene selectivity of 98% with side products of methane, ethylene, and ethane. The four
reactors are run in parallel with 3 reactors running at any given time while the fourth is regenerating catalyst. Each reactor runs for 6 hours and then is allowed 2 hours to shut down, start up, and regenerate the catalyst. The catalyst is regenerated by feeding air at 1094 °F for one hour to combust carbon deposition. Each reactor contains 326 tubes of 6-inch diameter to ensure heat transfer to the center of the tube. The tubes are 50 feet in length and are contained within a furnace burning 54 MMBTU/hr of natural gas to maintain a reactor temperature of 1094 °F with the endothermic conversion of propane to propylene. The tubes make up a total reactor volume of 3,200 cubic feet for each reactor. Each tube is composed of stainless steel 304 and has a wall thickness of 1.8 inches to ensure structural integrity at high temperature. The tubes are packed with 0.2-0.6% Pt-Sn/ZnAl₂O₅ catalyst with a weighted hourly space velocity of 2 hr⁻¹ with propane. The catalyst packing has a void fraction of 0.7 which gives a pressure drop of 16.7 psi and residence time of 2 seconds. The reactor weighs 2,650,000 lbs and has total bare module cost of $104,419,000 including catalyst costs.

Reactors R-102, R-104, R-106, and R-108 are identical reactors that operate in series with the reformer reactors. These reactors are fed the product streams of the reformers along with 10% molar ratio of pure oxygen to propane to combust hydrogen and push the overall propane conversion to 49%. 17,800 pounds of propylene are generated per hour by each reactor. These reactors have lower propylene selectivity of 88% and produce carbon monoxide and carbon dioxide when propane and propylene combust with oxygen. Oxygen is dispersed evenly across the catalyst bed to achieve optimal conversion. The oxygen feed is assumed to be pure; if trace amounts of nitrogen are present, they will remain inert throughout the process until they are removed by the cryogenic distillation unit DC-202. These reactors have the same operating cycle as the reformers preceding them with 6 hours of run time and 2 hours of dead time with 3
reactors operating at any given time. Each reactor operates adiabatically with a feed temperature of 1094 °F and pressure of 56.3 psi. The overall system of reactions is exothermic producing 68 MMBTU/hr of heat which causes the products increase in temperature to 1211 °F and drop to a pressure of 52.5 psi. The reactor is a pressure vessel with 12 feet in diameter and 18 feet in length and a total volume of 2,178 cubic feet. The wall thickness is 0.625 inches of stainless steel 304 and each reactor weighs 27,600 pounds. The reactor is packed with 0.2-0.6% Pt-Sn/ZnAl₂O₅ catalyst with a weighted hourly space velocity of 2 hr⁻¹ with propane. The bed has a void space of 0.7 which gives a residence time of 2 seconds. The total bare module cost of each reactor and its catalyst packing is $ 5,621,000.

Membrane

The membrane, M-500, is used to provide the final separation of propene from propane. With a selectivity of 35, permeance of 2.77 E-8, and pressure drop of 555 psi from feed to permeate, the required surface area of the membrane is 281,700 ft². The cost of the YSZ support necessary to manufacture the membrane costs $1,206,900. The cost of zinc nitrate hexahydrate is $1,002,500. The cost of 2-methylimidazole used in the manufacture of the membrane costs $27,457,000. This results in a membrane total cost of $30,873,000.

It should be noted that these cost estimates are based on prices obtained online for the purchase of small quantities of the raw materials required for manufacturing the membrane. These costing may be off by a factor of up to ten and more research is necessary to determine more accurate raw material pricing and manufacturing costs.

The feed stream, S-506, enters the membrane at a temperature of 257 F and pressure of 575 psi. This feed stream is 68.4% propene by mass and has a flow rate of 282,400 lb/hr. The retentate, S-511, has a flow rate of 105,300 lb/hr and is only 16% propene. The retentate is
obtained at 110 F and 20 psi. The permeate product stream, S-507, flowing at 177,100 lb/hr is 99.5% propene by mass and is obtained at 94 F and 20 psi.
## Specification Sheets

### Distillation Columns and Associated Equipment

### DISTILLATION COLUMN

<table>
<thead>
<tr>
<th>Identification: Item No.</th>
<th>Distillation Column</th>
<th>Item No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DC-202</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

### Function:
Remove hydrogen, carbon monoxide and light components

### Operation:
Continuous

### Type:
N/A

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-208</td>
<td>S-501</td>
<td>S-210</td>
</tr>
</tbody>
</table>

### Flow rate (lb/hr)
| Propane   | 418,458 | 406,818 | 11,640   |
| Propene   | 424     | 125     | -96      |
| Hydrogen  | 300     | 282     | 270      |

### Temperature (°F)
| Propane   | 424     | 125     | -96      |
| Propene   | 194,983 | 192,843 | 2,140    |
| Hydrogen  | 6,691   | 0       | 6,690    |
| Oxygen    | 0       | 0       | 0        |
| Water     | 389     | 389     | 0        |
| Carbon Monoxide | 1,635 | 0  | 1,635 |
| Carbon Dioxide     | 311    | 3       | 308      |
| Methane    | 287     | 0       | 287      |
| Ethane     | 247     | 6       | 241      |
| Ethene     | 281     | 2       | 279      |

### Design Data:
- Tray Type: Sieve
- Packing Material: Metal
- Tray Spacing (ft): 2
- Vendor: KOCH
- Column Height (ft): 48
- Column Diameter (ft): 23.1
- Material of Construction: Carbon Steel(SA-285 Grade C) & Stainless Steel
- Number of Stages: 20
- Feed Stage: 19
- Reflux Ratio: 4.5
- Boilup Ratio: 1.12

### Cost of utilities/year:
- Refrigeration -150°F $54,158,000.00
- Natural Gas $857,000.00

### Purchase Cost:
- $1,460,000.00

### Bare Module Cost:
- $6,000,000.00

### Associated Costs:
- Condenser: $1,200,000.00
- Reboiler System: $2,182,000.00
- Reflux Accumulator: $295,000.00
- Reflux Pump: $256,000.00

### Total Bare Module Cost:
- $9,933,000.00

### Comments:
Average cost of carbon steel and stainless steel used in costing factors
# REFLUX PUMP

<table>
<thead>
<tr>
<th>Identification:</th>
<th>P-203</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function:</td>
<td>Pump the contents of the reflux accumulator back to DC-202</td>
</tr>
<tr>
<td>Operation:</td>
<td>continuous</td>
</tr>
<tr>
<td>Design Data:</td>
<td></td>
</tr>
<tr>
<td>Type:</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>Material:</td>
<td>Cast Iron</td>
</tr>
<tr>
<td>Flow Rate (gpm):</td>
<td>34403</td>
</tr>
<tr>
<td>Head (ft):</td>
<td>334.4</td>
</tr>
<tr>
<td>Rating:</td>
<td>1496kW</td>
</tr>
<tr>
<td>Utilities Electricity</td>
<td>$917,288.00</td>
</tr>
<tr>
<td>Total Bare Module Cost</td>
<td>$256,000.00</td>
</tr>
<tr>
<td><strong>REBOILER PUMP</strong></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Identification:</strong></td>
<td>P-205</td>
</tr>
<tr>
<td><strong>Function:</strong></td>
<td>Increase pressure in the reboiler RB-202</td>
</tr>
<tr>
<td><strong>Operation:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Design Data:</strong></td>
<td></td>
</tr>
<tr>
<td>Type:</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>Material:</td>
<td>Cast Iron</td>
</tr>
<tr>
<td>Flow Rate (gpm):</td>
<td>1800</td>
</tr>
<tr>
<td>Head (ft):</td>
<td>493</td>
</tr>
<tr>
<td>Rating:</td>
<td>24kW</td>
</tr>
<tr>
<td>Utilities Electricity</td>
<td>$</td>
</tr>
<tr>
<td>Total Bare Module Cost</td>
<td>$</td>
</tr>
</tbody>
</table>
### REFLUX ACCUMULATOR

<table>
<thead>
<tr>
<th>Identification:</th>
<th>RA-202</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function:</td>
<td>Acumulate reflux in DC-202</td>
</tr>
<tr>
<td>Operation:</td>
<td>continuous</td>
</tr>
<tr>
<td><strong>Design Data:</strong></td>
<td></td>
</tr>
<tr>
<td>Type:</td>
<td></td>
</tr>
<tr>
<td>Material:</td>
<td></td>
</tr>
<tr>
<td>Diameter (ft):</td>
<td>30.8</td>
</tr>
<tr>
<td>Length (ft):</td>
<td>61.6</td>
</tr>
<tr>
<td>Capacity (ft^3):</td>
<td>45990</td>
</tr>
<tr>
<td>Residence Time (min):</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total Bare Module Cost</strong></td>
<td><strong>$ 295,000.00</strong></td>
</tr>
</tbody>
</table>
## CONDENSER

| Identification: | CN-202 |
| Function:       | To condense overhead contents of DC-202 |
| Operation:      | Continuous |

### Design Data:

| Type:            | Shell & Tube |
| Subtype:         | Fixed Head   |
| Material:        | Carbon Steel |
| Length (ft):     | 20           |
| Area (ft²):      | 17,795       |
| Condenser Duty (MMBTU): | 147         |
| Condenser Pressure (psia): | 270         |

<p>| Utilities (cooling Water) | $ | 54,158,000.00 |
| Total Bare Module Cost    | $ | 1,200,000.00  |</p>
<table>
<thead>
<tr>
<th><strong>REBOILER</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identification:</strong></td>
</tr>
<tr>
<td><strong>Function:</strong></td>
</tr>
<tr>
<td><strong>Operation:</strong></td>
</tr>
<tr>
<td><strong>Design Data:</strong></td>
</tr>
<tr>
<td><strong>Type:</strong></td>
</tr>
<tr>
<td><strong>Subtype:</strong></td>
</tr>
<tr>
<td><strong>Material:</strong></td>
</tr>
<tr>
<td><strong>Length(ft):</strong></td>
</tr>
<tr>
<td><strong>Area (ft^2):</strong></td>
</tr>
<tr>
<td><strong>Reboiler Duty (MMBTU):</strong></td>
</tr>
<tr>
<td><strong>Total Bare Module Cost</strong></td>
</tr>
</tbody>
</table>
# DISTILLATION COLUMN

**Identification:**
- Item: Distillation Column
- Item No.: DC-500
- No. Required: 1

**Function:** To provide an initial separation of propene from propane.

**Operation:** Continuous

**Type:** N/A

### Stream ID

<table>
<thead>
<tr>
<th>Function</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-501</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-503</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-502</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Item Specifications

- **Flow rate (lb/hr):**
  - Feed: 407675
  - Bottoms: 125287
  - Overhead: 282388

- **Temperature (°F):**
  - Feed: 125
  - Bottoms: 121
  - Overhead: 103

- **Pressure (psia):**
  - Feed: 282
  - Bottoms: 245
  - Overhead: 225

### Composition (lb/hr)

<table>
<thead>
<tr>
<th>Component</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>213575</td>
<td>124413</td>
<td>89162.01</td>
</tr>
<tr>
<td>Propene</td>
<td>193699</td>
<td>484</td>
<td>193216</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.00134751</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>390</td>
<td>390</td>
<td>0</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>0.02</td>
<td>0</td>
<td>0.02</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>2.54</td>
<td>0</td>
<td>2.54</td>
</tr>
<tr>
<td>Methane</td>
<td>0.03</td>
<td>0</td>
<td>0.03</td>
</tr>
<tr>
<td>Ethane</td>
<td>6.3</td>
<td>0</td>
<td>6.3</td>
</tr>
<tr>
<td>Ethene</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

### Design Data:

- Column Diameter (ft): 30
- Material of Construction: Carbon Steel
- Number of Stages: 90
- Feed Stage: 45
- Reflux Ratio: 5
- Boilup Ratio: 14.13

### Cost of Utilities/year:

- Natural gas: $3,435,000
- Cooling water: $1,195,000.00
- Electricity: $204,000.00

### Purchase Cost:

- $10,875,000.00

### Bare Module Cost:

- $45,240,000.00

### Associated Costs:

- Condenser: $1,066,000.00
- Reboiler: $7,458,867.00
- Reboiler Pump: $19,000.00
- Reflux Accumulator: $1,172,000.00
- Reflux Pump: $80,000.00

### Total Bare Module Cost:

- $55,035,867.00
# REFLUX PUMP

<table>
<thead>
<tr>
<th>Identification:</th>
<th>P-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function:</td>
<td>Pump the contents of the reflux accumulator back to DC-500</td>
</tr>
<tr>
<td>Operation:</td>
<td>continuous</td>
</tr>
<tr>
<td>Design Data:</td>
<td>Type: Centrifugal</td>
</tr>
<tr>
<td></td>
<td>Material: Cast Iron</td>
</tr>
<tr>
<td></td>
<td>Flow Rate (gpm): 7086</td>
</tr>
<tr>
<td></td>
<td>Head (ft): 337</td>
</tr>
<tr>
<td></td>
<td>Rating: 368kW</td>
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<tr>
<td>Utilities Electricity</td>
<td>$188,942.00</td>
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<tr>
<td>Total Bare Module Cost</td>
<td>$79,630.00</td>
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# REBOILER PUMP

<table>
<thead>
<tr>
<th>Identification:</th>
<th>P-501</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function:</td>
<td>Increase pressure in the reboiler RB-500</td>
</tr>
<tr>
<td>Operation:</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Data:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Centrifugal</td>
</tr>
<tr>
<td>Material:</td>
<td>Cast Iron</td>
</tr>
<tr>
<td>Flow Rate (gpm):</td>
<td>555</td>
</tr>
<tr>
<td>Head (ft):</td>
<td>493</td>
</tr>
<tr>
<td>Rating:</td>
<td>24kW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Utilities Electricity</th>
<th>$14,788.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Bare Module Cost</td>
<td>$18,886.00</td>
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</tbody>
</table>
**REFLUX ACCUMULATOR**

<table>
<thead>
<tr>
<th>Identification:</th>
<th>RA-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function:</td>
<td>Accumulate reflux in DC-500</td>
</tr>
<tr>
<td>Operation:</td>
<td>continuous</td>
</tr>
<tr>
<td>Design Data:</td>
<td></td>
</tr>
<tr>
<td>Type:</td>
<td></td>
</tr>
<tr>
<td>Material:</td>
<td></td>
</tr>
<tr>
<td>Diameter (ft):</td>
<td>18</td>
</tr>
<tr>
<td>Length (ft):</td>
<td>36</td>
</tr>
<tr>
<td>Capacity (ft³):</td>
<td>9473</td>
</tr>
<tr>
<td>Residence Time (min):</td>
<td>5</td>
</tr>
<tr>
<td>Total Bare Module Cost</td>
<td>$ 1,172,213.00</td>
</tr>
</tbody>
</table>
## CONDENSER

<table>
<thead>
<tr>
<th>Identification:</th>
<th>CN-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function:</td>
<td>To condense overhead contents of DC-500</td>
</tr>
<tr>
<td>Operation:</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

### Design Data:

<table>
<thead>
<tr>
<th>Type:</th>
<th>Shell &amp; Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtype:</td>
<td>Fixed Head</td>
</tr>
<tr>
<td>Material:</td>
<td>Carbon Steel</td>
</tr>
<tr>
<td>Length (ft.):</td>
<td>20</td>
</tr>
<tr>
<td>Area (ft^2):</td>
<td>27636</td>
</tr>
<tr>
<td>Condenser Duty (MMBTU):</td>
<td>227</td>
</tr>
<tr>
<td>Condenser Pressure (psia):</td>
<td>225</td>
</tr>
</tbody>
</table>

| Utilities (cooling Water) | $1,195,520.00 |
| Total Bare Module Cost    | $1,066,058.00 |
## REBOILER

<table>
<thead>
<tr>
<th>Identification:</th>
<th>RB-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function:</td>
<td>Vaporize bottoms of DC-500</td>
</tr>
<tr>
<td>Operation:</td>
<td>Continuous</td>
</tr>
<tr>
<td>Design Data:</td>
<td></td>
</tr>
<tr>
<td>Type:</td>
<td>Shell &amp; Tube</td>
</tr>
<tr>
<td>Subtype:</td>
<td>Kettle Vaporizer</td>
</tr>
<tr>
<td>Material:</td>
<td>Carbon Steel</td>
</tr>
<tr>
<td>Length(ft):</td>
<td>20</td>
</tr>
<tr>
<td>Area (ft²):</td>
<td>18363</td>
</tr>
<tr>
<td>Reboiler Duty (MMBTU):</td>
<td>220</td>
</tr>
<tr>
<td>Total Bare Module Cost</td>
<td>$729,080.00</td>
</tr>
</tbody>
</table>
# CARBON DIOXIDE CAPTURE SYSTEM

**Identification:**
- Item: Composite
- Item No.: AB-201
- No. Required: 1

**Function:** Remove carbon dioxide from reactor effluent prior to C3 separation

**Operation:** Continuous

**Type:** N/A

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-205</td>
<td>S-218</td>
<td>S-205</td>
</tr>
</tbody>
</table>

**Flow rate (lb/hr):**
- Feed: 423494
- Bottoms: N/A
- Overhead: 418458

**Temperature (°F):**
- Feed: 176
- Bottoms: N/A
- Overhead: 176

**Pressure (psia):**
- Feed: 30
- Bottoms: N/A
- Overhead: 25

**Composition (lb/hr):**
- Propane: 213634
- Propene: 194983
- Hydrogen: 6697
- Oxygen: 0
- Water: 548
- Carbon Monoxide: 1635
- Carbon Dioxide: 5181
- Methane: 287
- Ethane: 247
- Ethene: 281

**Operating Costs (including utilities):** $1,330,000.00

**Total Bare Module Cost:** $3,170,000.00

**Comments:**
- Water and MEA present in bottoms composition.
- Design data provided Hwang, etc., 2013.
## WATER ADSORPTION SYSTEM

**Identification:**
- Item: Adsorption Column
- Item No.: AD-201
- No. Required: 2

**Function:** Remove water from reactor effluent prior to C3 separation

**Operation:** Continuous

**Type:** N/A

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-204</td>
<td>S-213</td>
<td>S-205</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow rate (lb/hr)</th>
<th>432420</th>
<th>422025</th>
<th>10395.36</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>176</td>
<td>176</td>
<td>176</td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>34.8</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

**Composition (lb/hr):**
- Propane: 213634
- Propene: 194983
- Hydrogen: 6697
- Oxygen: 0
- Water: 10967
- Carbon Monoxide: 1635
- Carbon Dioxide: 5181
- Methane: 290
- Ethane: 250
- Ethene: 281

**Design Data:**
- Packing Type: Molecular Sieve
- Packing Material: 3A Molecular Sieve
- Packing Weight (lb): 250,000
- Column Height (ft): 35.70
- Column Diameter (ft): 11.9
- Material of Construction: Carbon Steel
- Total cycle time (hr): 8
- Regeneration time (hr): 7
- Transition Time (hr): 1

**Cost of utilities/year:**
- Electricity: $28,350.00
- Nitrogen (purge): $333,000.00
- Chilled Water: $1,340,000.00
- Natural Gas: $27,700.00

**Purchase Cost:** $209,000.00

**Bare Module Cost:** $869,440.00

**Associated Costs:**
- Packing: $70,000.00
- Blower: $125,190.00
- Chiller: $109,140.00
- Heater: $1,000,000.00
- Heat Exchanger: $738,000.00

**Total Bare Module Cost:** $3,870,000.00

**Comments:**
- Nitrogen utility to purge hydrocarbons from columns
- Cost is for both columns and associated equipment
## Compressors

### Compressor Details

**Identification:**
- **Item:** Compressor
- **Item No.:** C-201
- **No. Required:** 1

**Function:** Compress air before cryogenic distillation

**Operation:** Continuous

**Type:** First compressor in two stage compressor process

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-206</td>
<td>S-207</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Flow Rate (lb/hr)</th>
<th>418458</th>
<th>418458</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>176</td>
<td>294</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>35</td>
<td>100</td>
</tr>
</tbody>
</table>

**Design Data:***
- **Construction Material:** Carbon Steel
- **Consumed (Hp):** 10,030
- **Drive Type:** Electric Motor Drive
- **Total Cooling Duty (BTU/hr):** $2.5\times10^7$

**Cost of utilities/year:**
- **Electricity:** $4,586,349.00
- **Gas:** $3,100,000.00
- **Total:** $7,130,000.00

**Comments:** Bare Module cost includes interstage cooling using recycled chilled water
## COMPRESSOR

<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item</th>
<th>Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>C-202</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Function:** Compress air before cryogenic distillation

**Operation:** Continuous

**Type:** Second compressor in two stage compressor process

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-207</td>
<td>S-208</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Flow Rate (lb/hr)</th>
<th>418458</th>
<th>418458</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>294</td>
<td>423</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>100</td>
<td>300</td>
</tr>
</tbody>
</table>

**Design Data:**
- **Construction Material:** Carbon Steel
- **Consumed (Hp):** 12,321
- **Drive Type:** Electric Motor Drice
- **Total Cooling Duty (BTU/hr):** $4.1 \times 10^7$

**Cost of utilities/year:**
- **Electricity:** $\$ 5,628,440.00$
- **3,700,000.00**
- **8,510,000.00**

**Purchase Cost:**
- $\$ 5,628,440.00$
- $\$ 3,700,000.00$
- $\$ 8,510,000.00$

**Bare Module Cost:**

**Comments:** Bare Module cost includes interstage cooling using recycled chilled water
# COMPRESSOR

<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item</th>
<th>Centrifugal Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>C-500</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Function:** To compress the propene product.

**Operation:** Continuous

**Type:** N/A

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-507</td>
<td>S-508</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Flow Rate (lb/hr)</th>
<th>177101</th>
<th>177101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>93.67574</td>
<td>338.2659</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>20</td>
<td>250</td>
</tr>
</tbody>
</table>

**Design Data:**
- Construction Material: Cast Iron/Carbon-Steel
- Power (Hp): 7,411
- Drive Type: Electric Motor Drive

**Cost of utilities/year:**
- Electricity $3,388,000.00
- Gas $2,442,000.00
- Steam $5,251,000.00

**Purchase Cost:**
- $2,442,000.00

**Bare Module Cost:**
- $5,251,000.00

**Comments:**
- COMPRESSOR
- To compress the propene product.
- Continuous
**Identification:**
- Item: Centrifugal Compressor
- Item No.: C-501
- No. Required: 1

**Function:**
To increase the pressure of the recycle stream.

**Operation:**
Continuous

**Type:**
N/A

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-514</td>
<td>S-515</td>
</tr>
</tbody>
</table>

| Air Flow Rate (lb/hr) | 207517  | 207517 |
| Temperature (°F)      | 71.6    | 180.7543 |
| Pressure (psi)        | 20      | 72.51887 |

**Design Data:**
- Construction Material: Cast Iron/Carbon-Steel
- Consumed/Produced power (Hp): 3776
- Drive Type: Electric Motor Drive

**Cost of utilities/year:**
- Electricity: $1,726,000.00

**Purchase Cost:**
- $1,424,000.00

**Bare Module Cost:**
- $3,062,000.00

**Comments:**
# TURBINE

<table>
<thead>
<tr>
<th>Identification: Item</th>
<th>Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No. T-201</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
</tr>
</tbody>
</table>

**Function:** Lower pressure prior to water removal  
**Operation:** Continuous  
**Type:** Single stage turbine with recoverable power  

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-201</td>
<td>S-202</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Flow Rate (lb/hr)</th>
<th>824709</th>
<th>824709</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>461</td>
<td>419</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>52.5</td>
<td>35</td>
</tr>
</tbody>
</table>

**Design Data:**  
- Construction Material: Carbon Steel  
- Produced power (Hp): 8,349

**Purchase Cost:** $795,000.00  
**Bare Module Cost:** $1,431,000.00
**Pumps**

<table>
<thead>
<tr>
<th>Identification</th>
<th>Item</th>
<th>Centrifugal Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>P-500</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Function</strong></td>
<td>To increase the pressure of the stream fed to the membrane.</td>
<td></td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td>Continuous</td>
<td></td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>Pump</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-502</td>
<td>S-504</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate (lb/hr)</th>
<th>282388</th>
<th>282388</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Temperature (°F)</td>
<td>103</td>
<td>106</td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>225</td>
<td>575</td>
</tr>
</tbody>
</table>

**Design Data:**

- Flow Rate (gpm): 1181
- Construction materials: Cast Iron

**Cost of utilities/year:**

- Electricity: $141,000.00
- Electricity: $13,300.00

**Bare Module Cost:**

- $44,000.00

**Total Bare Module Cost:**

- $44,000.00
# Heat Exchangers

## HEAT EXCHANGER

<table>
<thead>
<tr>
<th>Identification</th>
<th>Item</th>
<th>Heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>HX-101</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function</th>
<th>Heats feed to the reformer using oxyreactor products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Continuous</td>
</tr>
<tr>
<td>Type</td>
<td>Floating head, shell and tube</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Tube Side</th>
<th>Shell Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream In</td>
<td>S-133</td>
<td>S-102</td>
</tr>
<tr>
<td>Stream Out</td>
<td>S-201</td>
<td>S-103</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate (lb/hr)</th>
<th>824709</th>
<th>806901</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Temperature (°F)</td>
<td>1211</td>
<td>279</td>
</tr>
<tr>
<td>Outlet Temperature (°F)</td>
<td>353</td>
<td>1094</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Data:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface area (ft²)</td>
</tr>
<tr>
<td></td>
<td>LMTD (°F)</td>
</tr>
<tr>
<td></td>
<td>Heat duty (MMBTU/hr)</td>
</tr>
<tr>
<td></td>
<td>Construction materials</td>
</tr>
<tr>
<td></td>
<td>Stainless steel/stainless steel</td>
</tr>
</tbody>
</table>

| Purchase Cost: | $210,000.00 |
| Bare Module Cost: | $1,313,000.00 |

| Comments: | Costed by combining a 12000sqft and 9000sqft heat exchangers |

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Tube Side</th>
<th>Shell Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream In</td>
<td>S-133</td>
<td>S-102</td>
</tr>
<tr>
<td>Stream Out</td>
<td>S-201</td>
<td>S-103</td>
</tr>
</tbody>
</table>
# Heat Exchanger

**Identification**

<table>
<thead>
<tr>
<th>Item</th>
<th>Heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>HX-201</td>
</tr>
<tr>
<td>No. Required</td>
<td>5</td>
</tr>
</tbody>
</table>

**Function**

Cool the products from the reactor complex

**Operation**

Continuous

**Type**

Floating head, shell and tube

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Tube Side</th>
<th>Shell Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate (lb/hr)</td>
<td>866281</td>
<td>CW</td>
</tr>
<tr>
<td>Inlet Temperature (°F)</td>
<td>419</td>
<td>80</td>
</tr>
<tr>
<td>Outlet Temperature (°F)</td>
<td>176</td>
<td>120</td>
</tr>
</tbody>
</table>

**Design Data:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area (ft²)</td>
<td>11000</td>
</tr>
<tr>
<td>Cooling Duty (MMBTU/hr)</td>
<td>550</td>
</tr>
<tr>
<td>Construction materials</td>
<td>Carbon Steel</td>
</tr>
</tbody>
</table>

**Cost of utilities/year:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Water</td>
<td>$2,799,524.00</td>
</tr>
</tbody>
</table>

**Purchase Cost:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$230,000.00</td>
</tr>
</tbody>
</table>

**Total Bare Module Cost:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$738,300.00</td>
</tr>
<tr>
<td>Identification</td>
<td>Heat exchanger</td>
</tr>
<tr>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Item No.</td>
<td>HX-500</td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
</tr>
<tr>
<td>Function</td>
<td>To increase the temperature of the stream fed to the membrane.</td>
</tr>
<tr>
<td>Operation</td>
<td>Continuous</td>
</tr>
<tr>
<td>Type</td>
<td>Floating head, shell and tube</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Tube Side</th>
<th>Shell Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream In</td>
<td>S-504</td>
<td>S-508</td>
</tr>
<tr>
<td>Stream Out</td>
<td>S-505</td>
<td>S-509</td>
</tr>
</tbody>
</table>

| Flow Rate (lb/hr) | 282388 | 177101 |
| Inlet Temperature (°F) | 106 | 338 |
| Outlet Temperature (°F) | 162 | 113 |

**Design Data:**

- Surface area (ft²): 2223
- LMTD (°F): 52.7
- Heat duty (MMBTU/hr): 17.55
- Construction materials: Carbon Steel

**Purchase Cost:**

- $52,000.00

**Bare Module Cost:**

- $164,000.00

**Comments:**
### STEAM BOILER

**Identification**  
Item: Heater  
Item No.: H-101  
No. Required: 1

**Function**  
Produces steam to be fed to the reformer

**Operation**  
Continuous

**Type**  
Fired heater

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-137</td>
<td>S-138</td>
</tr>
</tbody>
</table>

| Flow Rate (lb/hr) | 385471 | 385471 |
| Temperature (°F)  | 166    | 467    |
| Pressure (psi)    | 73     | 73     |

**Design Data:**  
Heat duty (MMBTU/hr): 438.439  
Construction materials: Stainless steel 304

**Cost of utilities/year:**  
Natural gas: $6,134,831.00

**Purchase Cost:**  
$40,000,000.00

**Bare Module Cost:**  
$74,400,000.00

**Total Bare Module Cost:**  
$74,400,000.00

**Comments:**  
Fed by fuel gas in S-142
## HEATER

<table>
<thead>
<tr>
<th>Identification</th>
<th>Item</th>
<th>Heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>H-500</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Function**: To vaporize the stream fed to the membrane.

**Operation**: Continuous

**Type**: Fired heater

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-505</td>
<td>S-506</td>
</tr>
</tbody>
</table>

| Flow Rate (lb/hr) | 282388     | 282388     |
| Temperature (°F)  | 162        | 257        |
| Pressure (psia)   | 575        | 575        |

**Design Data**:
- Heat duty (MMBTU/hr) 54.33
- Construction materials Carbon Steel

**Cost of utilities/year**: Recycled hydrogen $847,000.00

**Purchase Cost**: $610,000.00

**Bare Module Cost**: $1,932,000.00

**Comments**: 
## HEATER

<table>
<thead>
<tr>
<th>Identification</th>
<th>Item</th>
<th>Heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>H-501</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Function**: To liquify the propene product.

**Operation**: Continuous

### Type

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-509</td>
<td>S-510</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate (lb/hr)</th>
<th>177101</th>
<th>177101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>113</td>
<td>100</td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>250</td>
<td>250</td>
</tr>
</tbody>
</table>

**Design Data**: Heat duty (MMBTU/hr) 24.566

**Cost of utilities/year**:  
- Cooling Water: $130,000.00  
- Construction materials: Carbon Steel

**Purchase Cost**:  
- Construction materials: $56,000.00

**Bare Module Cost**:  
- Construction materials: $178,000.00

**Comments**:  
- Temperature (ºF): 113  
- Pressure (psia): 250  
- Flow Rate (lb/hr): 177101  
- Stream ID: S-509, S-510  
- Function: To liquify the propene product.  
- Operation: Continuous
### HEATER

<table>
<thead>
<tr>
<th>Identification</th>
<th>Item</th>
<th>Heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>H-502</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Function**: To vaporize the recycle stream.

**Operation**: Continuous

**Type**: Fired heater

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Stream In</th>
<th>Stream Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-513</td>
<td>S-514</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow Rate (lb/hr)</th>
<th>207517</th>
<th>207517</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>-29</td>
<td>72</td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

**Design Data**:
- Heat duty (MMBTU/hr): 10.497
- Construction materials: Carbon Steel

<table>
<thead>
<tr>
<th>Cost of utilities/year:</th>
<th>Natural gas</th>
<th>$164,000.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Cost:</td>
<td>$332,000.00</td>
<td></td>
</tr>
<tr>
<td>Bare Module Cost:</td>
<td>$727,000.00</td>
<td></td>
</tr>
</tbody>
</table>

**Comments**: |
### Reactors

<table>
<thead>
<tr>
<th><strong>Identification</strong></th>
<th><strong>Vertical Vessel</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>R-101, R-103, R-105, R-107</td>
</tr>
<tr>
<td>No. Required</td>
<td>4</td>
</tr>
</tbody>
</table>

**Function**: Produces propene through propane dehydrogenation

**Operation**: Continuous

**Type**: N/A

<table>
<thead>
<tr>
<th><strong>Stream ID</strong></th>
<th><strong>Inlet</strong></th>
<th><strong>Outlet</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>S-106</td>
<td>S-113</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Temperature (°F)</strong></th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1094</td>
<td>1094</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Pressure (psi)</strong></th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>73</td>
<td>56.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Flow rate (lb/hr)</strong></th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>806901</td>
<td>806901</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Composition (lb/hr)</strong></th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>406720</td>
<td>278858</td>
</tr>
<tr>
<td>Propene</td>
<td>13936</td>
<td>135420</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0</td>
<td>5812</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>386235</td>
<td>386235</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>2.25</td>
<td>2.25</td>
</tr>
<tr>
<td>Methane</td>
<td>0.03</td>
<td>203</td>
</tr>
<tr>
<td>Ethane</td>
<td>5.56</td>
<td>120</td>
</tr>
<tr>
<td>Ethene</td>
<td>1.76</td>
<td>250</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th><strong>Design Data</strong>:</th>
<th>Number of tubes:</th>
<th>326</th>
<th>Catalyst:</th>
<th>2.6%Pt-Sn/ZnAl2O5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube diameter (ft):</td>
<td>0.5</td>
<td></td>
<td>Propane conversion:</td>
<td>0.32</td>
</tr>
<tr>
<td>Tube length (ft):</td>
<td>50</td>
<td></td>
<td>Propylene selectivity:</td>
<td>0.976</td>
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<tr>
<td>Total volume (ft³):</td>
<td>3203</td>
<td></td>
<td>C1-C2 selectivity:</td>
<td>0.024</td>
</tr>
<tr>
<td>Wall thickness (in):</td>
<td>1.8</td>
<td></td>
<td>COx selectivity:</td>
<td>0.1</td>
</tr>
<tr>
<td>Vessel weight (lb):</td>
<td>2,649,700</td>
<td></td>
<td>Particle diameter (in):</td>
<td>0.1</td>
</tr>
<tr>
<td>Velocity (ft/s):</td>
<td>32</td>
<td></td>
<td>Bulk density (g/cm³):</td>
<td>0.336</td>
</tr>
<tr>
<td>Residence time (sec):</td>
<td>2</td>
<td></td>
<td>Catalyst weight (lb):</td>
<td>67655</td>
</tr>
<tr>
<td>WHSV (1/hr):</td>
<td>2</td>
<td></td>
<td>Regeneration time (hr):</td>
<td>1</td>
</tr>
<tr>
<td>Void fraction:</td>
<td>0.7</td>
<td></td>
<td>Duty (MMBTU/hr)</td>
<td>53.99</td>
</tr>
<tr>
<td>Pressure drop (psi):</td>
<td>16.7</td>
<td></td>
<td>Construction material:</td>
<td>Stainless Steel 304</td>
</tr>
</tbody>
</table>

**Cost of utilities/year**: Natural gas $2,525,000.00

**Purchase Cost**: $25,458,000.00

**Bare Module Cost**: $97,089,000.00

**Associated Costs**: Catalyst $7,330,000.00

**Total Bare Module Cost**: $104,419,000.00

**Comments**: R-103, R-105, R-107 are identical to R-101
# OXYREACTOR

<table>
<thead>
<tr>
<th>Identification</th>
<th>Item No.</th>
<th>No. Required</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

**Function**: Produces propene through propane oxydehydrogenation  
**Operation**: Continuous

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Inlet</th>
<th>Inlet</th>
<th>Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-113</td>
<td>S-129</td>
<td>S-114</td>
</tr>
</tbody>
</table>

| Temperature (°F) | 1094 | 1094 | 1211 |
| Pressure (psi)   | 56.3 | 56.3 | 52.5 |
| Flow rate (lb/hr) | 806901 | 23999 | 824709 |

<table>
<thead>
<tr>
<th>Composition (lb/hr)</th>
<th>Propane</th>
<th>Propene</th>
<th>Hydrogen</th>
<th>Oxygen</th>
<th>Water</th>
<th>Carbon monoxide</th>
<th>Carbon dioxide</th>
<th>Methane</th>
<th>Ethane</th>
<th>Ethene</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>278858</td>
<td>0</td>
<td>5812</td>
<td>0</td>
<td>386235</td>
<td>0.01</td>
<td>2.25</td>
<td>203</td>
<td>120</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Data:</th>
<th>Reactor diameter (ft):</th>
<th>12</th>
<th>Catalyst:</th>
<th>.2-.6%Pt-Sn/ZnAl2O4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reactor length (ft):</td>
<td>18</td>
<td>Propane conversion:</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Total volume (ft³):</td>
<td>2178</td>
<td>Propylene selectivity:</td>
<td>0.877</td>
</tr>
<tr>
<td></td>
<td>Wall thickness (in):</td>
<td>0.625</td>
<td>C1-C2 selectivity:</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>Vessel weight (lb):</td>
<td>27,600</td>
<td>COx selectivity:</td>
<td>0.108</td>
</tr>
<tr>
<td></td>
<td>Velocity (ft/s):</td>
<td>20</td>
<td>Particle diameter (in):</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Residence time (sec):</td>
<td>2</td>
<td>Bulk density (g/cm³):</td>
<td>0.336</td>
</tr>
<tr>
<td></td>
<td>WHSV (1/hr)</td>
<td>2</td>
<td>Catalyst weight (lb):</td>
<td>46006</td>
</tr>
<tr>
<td></td>
<td>Void fraction:</td>
<td>0.7</td>
<td>Regeneration time (hr):</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Pressure drop (psi):</td>
<td>3.8</td>
<td>Duty (MMBTU/hr):</td>
<td>-17.086</td>
</tr>
<tr>
<td></td>
<td>Construction material:</td>
<td>Stainless Steel 304</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Cost of utilities/year: | $ | |
| Purchase Cost: | $ | 154,000.00 |
| Bare Module Cost: | $ | 638,000.00 |
| Associated Costs: | Catalyst | $ | 4,983,000.00 |
| Total Bare Module Cost: | $ | 5,621,000.00 |

**Comments**: R-104, R-106, R-108 are identical to R-102
## MEMBRANE

**Identification:**
- Item: ZIF-8 Membrane
- Item No.: M-500
- No. Required: 1

**Function:**
To provide an final separation of propene from propane.

**Operation:**
Continuous

**Type:**
N/A

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Feed</th>
<th>Permeate</th>
<th>Retentate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S-506</td>
<td>S-507</td>
<td>S-511</td>
</tr>
</tbody>
</table>

| Flow rate (lb/hr) | 282388 | 177101 | 105287 |
| Temperature (°F)  | 257    | 94     | 110    |
| Pressure (psia)   | 575    | 20     | 20     |

<table>
<thead>
<tr>
<th>Composition (lb/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
</tr>
<tr>
<td>Propene</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Data:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selectivity (propylene/propane)</td>
</tr>
<tr>
<td>Propene permeance (mol/m²/Pa)</td>
</tr>
<tr>
<td>Area (ft²)</td>
</tr>
<tr>
<td>Pressure drop: feed to permeate</td>
</tr>
<tr>
<td>Pressure drop: feed to retentate</td>
</tr>
</tbody>
</table>

**Purchase Cost:**
- $ 29,666,000.00

**Bare Module Cost:**
- $ 55,178,000.00

**Associated Costs:**
- YSZ Support: $ 1,206,000.00

**Total Bare Module Cost:**
- $ 56,384,000.00

**Comments:**

Equipment Cost Summary

The summary of all equipment purchase and bare module costs is presented in the table below. The total cost for plant equipment is $676 MM, 85% of which is attributed to the cost of our reactor complex. This was anticipated to be the largest cost in our process due to the additional capacity needed for regeneration and the requirements of the reformers and oxyreactors. This number is large but in sync with similar projects in industry. A discussion of the reformers and their material needs is discussed in the unit description section and economic analysis section.

HX-101, which exchanges heat between the feed and effluent of the reactor complex, is the most expensive heat exchanger due to its massive area. This large area was required to minimize utilities and maximize energy efficiency.

The C3 separation was also a significant part of the equipment cost due to the high costs of the distillation column and membrane. The high costs of the hybrid approach compared to using just a distillation column are discussed in the other considerations section.
<table>
<thead>
<tr>
<th>Unit Name</th>
<th>$C_p$</th>
<th>$F_{BM}$</th>
<th>Associated Costs</th>
<th>$C_{BM}$</th>
<th>Quantity</th>
<th>Total $C_{BM}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactor Complex</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-101</td>
<td>$40,000,000.00$</td>
<td>1.86</td>
<td>$0.00$</td>
<td>$74,400,000.00$</td>
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<td>$74,400,000.00$</td>
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<tr>
<td>H-102</td>
<td>$1,601,000.00$</td>
<td>2.56</td>
<td>$0.00$</td>
<td>$4,098,000.00$</td>
<td>1</td>
<td>$4,098,000.00$</td>
</tr>
<tr>
<td>HX-101</td>
<td>$210,000.00$</td>
<td>6.25</td>
<td>$0.00$</td>
<td>$1,313,000.00$</td>
<td>1</td>
<td>$1,313,000.00$</td>
</tr>
<tr>
<td>R-101, R-103, R-105, R-107</td>
<td>$25,458,000.00$</td>
<td>3.81</td>
<td>$7,330,000.00$</td>
<td>$97,089,000.00$</td>
<td>4</td>
<td>$417,676,000.00$</td>
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<tr>
<td>R-102, R-104, R-106, R-108</td>
<td>$154,000.00$</td>
<td>4.14</td>
<td>$4,983,000.00$</td>
<td>$638,000.00$</td>
<td>4</td>
<td>$22,484,000.00$</td>
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<td><strong>Subtotal</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$519,971,000.00$</td>
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<td><strong>Water Adsorption</strong></td>
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<td>T-201</td>
<td>$795,000.00$</td>
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<td>HX-201</td>
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<td>$0.00$</td>
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<td>AD-201</td>
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<td>2</td>
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<td></td>
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<td>$6,174,000.00$</td>
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<td><strong>CO2 Absorption</strong></td>
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<tr>
<td>AB-201</td>
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<td>$3,170,000.00$</td>
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<td><strong>Subtotal</strong></td>
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<td>$3,170,000.00$</td>
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<td><strong>Distillation Column</strong></td>
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<td>C-201</td>
<td>$3,100,000.00$</td>
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<td>C-202</td>
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<td>DC-202</td>
<td>$1,460,000.00$</td>
<td>4.16</td>
<td>$3,933,000.00$</td>
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<td>$9,933,000.00$</td>
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<td><strong>Subtotal</strong></td>
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<td>$25,573,000.00$</td>
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<td><strong>Hybrid C3 Splitter</strong></td>
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<td>DC-500</td>
<td>$13,050,000.00$</td>
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<td>$3,066,000.00$</td>
<td>$50,115,000.00$</td>
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<td>$53,181,000.00$</td>
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<td>HX-500</td>
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<td>H-500</td>
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<td>$0.00$</td>
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<td>$1,932,000.00$</td>
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<td>M-500</td>
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<td>$1,206,000.00$</td>
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<td>$56,384,000.00$</td>
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<tr>
<td>C-500</td>
<td>$2,442,000.00$</td>
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<td>H-501</td>
<td>$56,000.00$</td>
<td>3.17</td>
<td>$0.00$</td>
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<td>H-502</td>
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<td>$0.00$</td>
<td>$727,000.00$</td>
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<td>$727,000.00$</td>
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<tr>
<td>C-501</td>
<td>$1,424,000.00$</td>
<td>2.15</td>
<td>$0.00$</td>
<td>$3,062,000.00$</td>
<td>1</td>
<td>$3,062,000.00$</td>
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<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$120,923,000.00$</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$675,811,000.00$</td>
</tr>
</tbody>
</table>
## Fixed-capital Investment Summary

**Table 5 summary of fixed costs**

<table>
<thead>
<tr>
<th>Fixed Costs</th>
<th>Summary of Fixed Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operations</strong></td>
<td></td>
</tr>
<tr>
<td>Operators per Shift:</td>
<td>1 (assuming 5 shifts)</td>
</tr>
<tr>
<td>Direct Wages and Benefits:</td>
<td>$40 per operator hour</td>
</tr>
<tr>
<td>Direct Salaries and Benefits:</td>
<td>15% of Direct Wages and Benefits</td>
</tr>
<tr>
<td>Operating Supplies and Services:</td>
<td>5% of Direct Wages and Benefits</td>
</tr>
<tr>
<td>Technical Assistance to Manufacturing:</td>
<td>$60,000.00 per year, for each Operator per Shift</td>
</tr>
<tr>
<td>Control Laboratory:</td>
<td>$65,000.00 per year, for each Operator per Shift</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>Wages and Benefits:</td>
<td>4.50% of Total Depreciable Capital</td>
</tr>
<tr>
<td>Salaries and Benefits:</td>
<td>25.00% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td>Materials and Services:</td>
<td>100.00% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td>Maintenance Overhead:</td>
<td>5.00% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td><strong>Operating Overhead</strong></td>
<td></td>
</tr>
<tr>
<td>General Plant Overhead:</td>
<td>7.12% of Maintenance and Operators Wages and Benefits</td>
</tr>
<tr>
<td>Mechanical Department Services:</td>
<td>2.40% of Maintenance and Operators Wages and Benefits</td>
</tr>
<tr>
<td>Employee Relations Department:</td>
<td>5.00% of Maintenance and Operators Wages and Benefits</td>
</tr>
<tr>
<td>Business Services:</td>
<td>7.40% of Maintenance and Operators Wages and Benefits</td>
</tr>
<tr>
<td><strong>Property Taxes and Insurance</strong></td>
<td></td>
</tr>
<tr>
<td>Property Taxes and Insurance:</td>
<td>2.00% of Total Depreciable Capital</td>
</tr>
<tr>
<td><strong>Straight Line Depreciation</strong></td>
<td></td>
</tr>
<tr>
<td>Direct Plant:</td>
<td>8.00% of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities</td>
</tr>
<tr>
<td>Allocated Plant:</td>
<td>0.00% of 1.18 times the Allocated Costs for Utility Plants and Related Facilities</td>
</tr>
<tr>
<td><strong>Other Annual Expenses</strong></td>
<td></td>
</tr>
<tr>
<td>Rental Fees (Office and Laboratory Space):</td>
<td>$0</td>
</tr>
<tr>
<td>Licensing Fees:</td>
<td>$0</td>
</tr>
<tr>
<td>Miscellaneous:</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Depletion Allowance</strong></td>
<td></td>
</tr>
<tr>
<td>Annual Depletion Allowance:</td>
<td>$0</td>
</tr>
</tbody>
</table>
Operating Cost- Cost of Manufacture

Our variable costs are broken down into raw materials, utility costs, labor costs, and other general expenses that scale with production. The general summary of all costs and investments is shown in the following table.
### Table 6 Investment summary

#### Variable Cost Summary

**Variable Costs at 100% Capacity:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selling / Transfer Expenses</td>
<td>$15,278,514</td>
</tr>
<tr>
<td>Direct Research</td>
<td>$24,445,622</td>
</tr>
<tr>
<td>Allocated Research</td>
<td>$2,546,419</td>
</tr>
<tr>
<td>Administrative Expense</td>
<td>$10,155,676</td>
</tr>
<tr>
<td>Management Incentive Compensation</td>
<td>$6,366,047</td>
</tr>
</tbody>
</table>

**Total General Expenses** $58,822,279

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials</td>
<td>$206,725,012</td>
</tr>
<tr>
<td>Byproducts</td>
<td>$0</td>
</tr>
<tr>
<td>Utilities</td>
<td>$77,399,839</td>
</tr>
</tbody>
</table>

**Total Variable Costs** $404,948,029

#### Fixed Cost Summary

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operations</strong></td>
<td></td>
</tr>
<tr>
<td>Direct Wages and Benefits</td>
<td>$416,000</td>
</tr>
<tr>
<td>Direct Salaries and Benefits</td>
<td>$62,400</td>
</tr>
<tr>
<td>Operating Supplies and Services</td>
<td>$24,960</td>
</tr>
<tr>
<td>Technical Assistance to Manufacturing</td>
<td>$300,000</td>
</tr>
<tr>
<td>Control Laboratory</td>
<td>$325,000</td>
</tr>
</tbody>
</table>

**Total Operations** $1,128,360

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wages and Benefits</td>
<td>$39,756,403</td>
</tr>
<tr>
<td>Salaries and Benefits</td>
<td>$9,939,101</td>
</tr>
<tr>
<td>Materials and Services</td>
<td>$39,756,403</td>
</tr>
<tr>
<td>Maintenance Overhead</td>
<td>$1,987,820</td>
</tr>
</tbody>
</table>

**Total Maintenance** $91,419,726

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operating Overhead</strong></td>
<td></td>
</tr>
<tr>
<td>General Plant Overhead</td>
<td>$3,562,347</td>
</tr>
<tr>
<td>Mechanical Department Services</td>
<td>$1,224,174</td>
</tr>
<tr>
<td>Employee Relations Department</td>
<td>$2,980,280</td>
</tr>
<tr>
<td>Business Services</td>
<td>$3,712,969</td>
</tr>
</tbody>
</table>

**Total Operating Overhead** $11,439,650

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Property Taxes and Insurance</strong></td>
<td></td>
</tr>
<tr>
<td>Property Taxes and Insurance</td>
<td>$17,669,512</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Other Annual Expenses</strong></td>
<td></td>
</tr>
<tr>
<td>Rental Fees (Office and Laboratory Space)</td>
<td>$ -</td>
</tr>
<tr>
<td>Licensing Fees</td>
<td>$ -</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>$ -</td>
</tr>
</tbody>
</table>

**Total Other Annual Expenses** $ -

**Total Fixed Costs** $121,077,248
Investment Summary

**Total Bare Module Costs:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabricated Equipment</td>
<td>$ 631,391,770</td>
</tr>
<tr>
<td>Process Machinery</td>
<td>$ -</td>
</tr>
<tr>
<td>Spares</td>
<td>$ -</td>
</tr>
<tr>
<td>Storage</td>
<td>$ -</td>
</tr>
<tr>
<td>Other Equipment</td>
<td>$ -</td>
</tr>
<tr>
<td>Catalysts</td>
<td>$ 49,252,000</td>
</tr>
<tr>
<td>Computers, Software, Etc.</td>
<td>$ -</td>
</tr>
</tbody>
</table>

**Total Bare Module Costs:** $ 680,643,770

**Direct Permanent Investment**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Site Preparations</td>
<td>$ 34,032,189</td>
</tr>
<tr>
<td>Cost of Service Facilities</td>
<td>$ 34,032,189</td>
</tr>
<tr>
<td>Allocated Costs for utility plants and related facilities</td>
<td>$ -</td>
</tr>
</tbody>
</table>

**Direct Permanent Investment** $ 748,708,147

**Total Depreciable Capital**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Contingencies &amp; Contractor Fees</td>
<td>$ 134,757,466</td>
</tr>
</tbody>
</table>

**Total Depreciable Capital** $ 834,756,613

**Total Permanent Investment**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Land</td>
<td>$ 17,699,512</td>
</tr>
<tr>
<td>Cost of Royalties</td>
<td>$ -</td>
</tr>
<tr>
<td>Cost of Plant Start-Up</td>
<td>$ 88,347,561</td>
</tr>
</tbody>
</table>

**Total Permanent Investment - Unadjusted** $ 989,492,617

**Site Factor** 1.00

**Total Permanent Investment** $ 989,492,617

**Working Capital**

<table>
<thead>
<tr>
<th>Item</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounts Receivable</td>
<td>$ 18,836,524</td>
<td>$ 9,418,262</td>
<td>$ 9,418,262</td>
</tr>
<tr>
<td>Cash Reserves</td>
<td>$ 7,363,125</td>
<td>$ 3,681,563</td>
<td>$ 3,681,563</td>
</tr>
<tr>
<td>Accounts Payable</td>
<td>$ (12,831,911)</td>
<td>(6,400,956)</td>
<td>(6,400,956)</td>
</tr>
<tr>
<td>Propene Inventory</td>
<td>$ 2,511,537</td>
<td>$ 1,255,788</td>
<td>$ 1,255,788</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>$ 682,612</td>
<td>$ 331,306</td>
<td>$ 331,306</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 16,571,886</strong></td>
<td><strong>$ 8,285,943</strong></td>
<td><strong>$ 8,285,943</strong></td>
</tr>
<tr>
<td><strong>Present Value at 8%</strong></td>
<td><strong>$ 15,344,339</strong></td>
<td><strong>$ 7,103,661</strong></td>
<td><strong>$ 5,777,649</strong></td>
</tr>
</tbody>
</table>

**Total Capital Investment** $ 1,418,518,516
Other Important Considerations

Plant Location

The proposed plant will be located in Middle East and will produce 700 kilotons of propene a year. This location was chosen to supply the propene needs in the Middle East and Europe (ICIS, 2016). The project will able to avoid the current supply glut of propene in China by focusing on supplying these markets. This location will also minimize propane costs because propane feed stocks are readily available from the oil refinery operations there.

Environmental Problems

Most of the fired heaters throughout the plant burn hydrogen to produce heat which produces hot air and steam. This effluent would need cooling to minimize the local environmental impact. The furnace effluents could be cooled with the incoming boiler water.

Propene emissions are not expected to exceed concentrations in the range of 0.1-4.8 parts per billion (ppb) in rural air and 4-10.5 ppb in urban air. Industrial samples have shown 7-260 ppb which is well below the 500 ppm guideline. It is therefore not considered that propene has any adverse effects on the global environment. Propane is non-toxic and will not create an environmental hazard if released as a liquid or vapor. The only damage potential exists if the vapor is ignited after spill (LFL-2.1% and UFL-10.1%).

Membrane Separation

An important aspect of the design to consider is that the membrane used, ZIF-8, has only ever been implemented on a laboratory scale. This means that all of the data obtained is based on lab results and is assumed to scale to our design parameters. However, this is unlikely to be true due to ideal conditions available in the lab which would be difficult to replicate in a production
plant. For this reason, more research must be done to determine if it is viable to create ZIF-8 membranes on a large enough scale as to be used in our design process for propene-propane separation.

**Plant Startup**

Special attention should be paid to the plant layout due to the potential hazard of the ignition materials in the process. Startup of the plant though out of scope of the project would increase costs above the predicted values in the profitability analysis provided in Seider, et al. This is due to the amount of heat integration on the process and the size of the recycle streams in the process. The change in the startup cost would however not have a large impact in the profitability of the process as this would ideally require only a singular startup.

**Health Information**

Propylene storage (liquid) form of propene has the potential to cause frostbite, permanent eye damage, and freeze burn. When handling the storage form of propene appropriate protective garments should be worn to prevent body contact with propene. In vapor form, propene is non-toxic in the recommended 500ppm and is toxic at high concentration (300,000ppm). Propene is not likely to cause cancer even when inhaled. Similar considerations should be made for propane as propylene when handling the liquid form of propane. The vapor form however may cause headaches, dizziness and myocardial irritability after excessive exposure.

**Physical Hazard Information**

Propylene is a flammable liquid and vapor with high vapor pressure. The lower flammability level for propylene is about 20,000 ppm, and the flash point is -162°F (-108°C). Liquid propylene may release flammable vapors below ambient temperature and forms a flammable mixture with air. Propylene vapor are heavier than air, and may travel long distance
to an ignition point or flash back. Therefore, propylene should be handled only with adequate ventilation and in areas where ignition sources have been removed. Propylene can only be stored in approved container such as bond and ground container to keep propylene away from flame, spark and excessive temperature. Empty product container or vessel should be returned to the Supplier or contact AmeriGas for safe disposal. If flammability levels are reached, evacuate the area and call emergency response personnel.

As a flammable liquefied gas under pressure, propane should be kept away from heat, spark, flame and all other ignition sources. Propane should store in a safe, authorized location with adequate since propane is heavier than air, and can collect in low areas that are without sufficient ventilation. If there is spill of the material, do not attempt to extinguish fire until propane source is isolated. Dry chemical, CO2, water and fog can be used as extinguishing media to put out fire. Propane, propylene and hydrogen concentrations are maintained above their UEL by feeding small oxygen concentrations to the reactors.
Profitability Analysis – Business Case

The economic analysis of this project is summarized in the following tables. Based on standard practice in the commodity chemicals industry, a conservative plant life of 20 years was chosen. At current prices of propene and propane, the process using the STAR technology and a hybrid membrane is not economical.

While the hybrid system for propene separation was fully developed in our analysis due to its previously stated optimization in terms of cost, the options of using only a distillation column and using only a membrane were also explored. The bare module cost of the hybrid system was found to be $120 million with a utility cost of $16.2 million. Using only a distillation column, the bare module cost increases to $182.5 million while the total utility cost per year decreases to $12.7 million. The membrane only separation system has the highest utility cost of $8 million per year and the highest bare module cost of $275 million. It should be noted that membrane costs may be off by as much as a factor of ten due to material costs being based on purchasing low quantity amounts whereas the membrane design calls for a large quantity of materials to be bought and used. This results in a very ambiguous set of values related to the bare module cost of the membrane and hybrid systems. Without having more accurate purchase price date for the materials used in making the membrane, it is difficult to draw a reasonable conclusion as to which method of separation is most cost effective and efficient.
Table 7 Profitability analysis

<table>
<thead>
<tr>
<th>General Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Title: Propane Dehydrogenation By Autothermal Reforming</td>
</tr>
<tr>
<td>Product: Propene</td>
</tr>
<tr>
<td>Plant Site Location: Middle East</td>
</tr>
<tr>
<td>Site Factor: 1.00</td>
</tr>
<tr>
<td>Operating Hours per Year: 7919</td>
</tr>
<tr>
<td>Operating Days Per Year: 330</td>
</tr>
<tr>
<td>Operating Factor: 0.9040</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>This Process will Yield</td>
</tr>
<tr>
<td>194,883 lb of Propene per hour</td>
</tr>
<tr>
<td>4,077,166 lb of Propene per day</td>
</tr>
<tr>
<td>1,543,284,240 lb of Propene per year</td>
</tr>
<tr>
<td>Price</td>
</tr>
<tr>
<td>$6.33 /lb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chronology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>2016</td>
</tr>
<tr>
<td>2017</td>
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<tr>
<td>2018</td>
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<td>2021</td>
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<tr>
<td>2030</td>
</tr>
<tr>
<td>2031</td>
</tr>
<tr>
<td>2032</td>
</tr>
</tbody>
</table>
# Equipment Costs

<table>
<thead>
<tr>
<th>Equipment Description</th>
<th>Rare Module Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-101</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>H-102</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>HX-101</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-101</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-102</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-103</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-104</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-105</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-106</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-107</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>R-108</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>T-201</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>HX-201</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>AD-201</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>AB-201</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>C-201</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>C-202</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>DC-202</td>
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</tr>
<tr>
<td>DC-500</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>P-500</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>HX-500</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>H-500</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>M-500</td>
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</tr>
<tr>
<td>C-500</td>
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<tr>
<td>H-501</td>
<td>Fabricated Equipment</td>
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<tr>
<td>H-502</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>C-501</td>
<td>Fabricated Equipment</td>
</tr>
<tr>
<td>.2-.6% P-Sn/ZnAl2O6</td>
<td>Catalysts</td>
</tr>
</tbody>
</table>
### Raw Materials

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Unit</th>
<th>Required Ratio</th>
<th>Cost of Raw Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>lb</td>
<td>1.2222 lb per lb of Propene</td>
<td>$0.114 per lb</td>
</tr>
<tr>
<td>Oxygen</td>
<td>lb</td>
<td>0.1362 lb per lb of Propene</td>
<td>$0.08 per lb</td>
</tr>
</tbody>
</table>

Total Weighed Average: $0.174 per lb of Propene

### Byproducts

<table>
<thead>
<tr>
<th>Byproduct</th>
<th>Unit</th>
<th>Ratio to Product</th>
<th>Byproduct Selling Price</th>
</tr>
</thead>
</table>

Total Weighed Average: $0.000E+00 per lb of Propene

### Utilities

<table>
<thead>
<tr>
<th>Utility:</th>
<th>Unit</th>
<th>Required Ratio</th>
<th>Utility Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA Capture System</td>
<td>unit</td>
<td>6.48E-10 unit per lb of Propene</td>
<td>$1330000.00 per unit</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>CF</td>
<td>0.00276 CF per lb of Propene</td>
<td>$0.078 per CF</td>
</tr>
<tr>
<td>Chilled Water</td>
<td>GJ</td>
<td>0.00017 GJ per lb of Propene</td>
<td>$5.000 per GJ</td>
</tr>
<tr>
<td>Cooling Water</td>
<td>gal</td>
<td>26.72 gal per lb of Propene</td>
<td>$1.000E+04 per gal</td>
</tr>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>0.1453 kWh per lb of Propene</td>
<td>$0.070 per kWh</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>MMBTU</td>
<td>0.00117 MMBTU per lb of Propene</td>
<td>$1.780 per MMBTU</td>
</tr>
<tr>
<td>Refrigeration (-150°F)</td>
<td>GJ</td>
<td>0.001 GJ per lb of Propene</td>
<td>$33.30 per GJ</td>
</tr>
</tbody>
</table>

Total Weighed Average: $0.050 per lb of Propene
<table>
<thead>
<tr>
<th>Variable Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Expenses:</strong></td>
</tr>
<tr>
<td>Selling / Transfer Expenses: 3.00% of Sales</td>
</tr>
<tr>
<td>Direct Research: 4.80% of Sales</td>
</tr>
<tr>
<td>Allocated Research: 0.50% of Sales</td>
</tr>
<tr>
<td>Administrative Expense: 2.00% of Sales</td>
</tr>
<tr>
<td>Management Incentive Compensation: 1.25% of Sales</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Working Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounts Receivable: 30 Days</td>
</tr>
<tr>
<td>Cash Reserves (excluding Raw Materials): 30 Days</td>
</tr>
<tr>
<td>Accounts Payable: 30 Days</td>
</tr>
<tr>
<td>Propylene Inventory: 4 Days</td>
</tr>
<tr>
<td>Raw Materials: 2 Days</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Permanent Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Site Preparations: 5.00% of Total Bare Module Costs</td>
</tr>
<tr>
<td>Cost of Service Facilities: 5.00% of Total Bare Module Costs</td>
</tr>
<tr>
<td>Allocated Costs for utility plants and related facilities: $0</td>
</tr>
<tr>
<td>Cost of Contingencies and Contractor Fees: 18.00% of Direct Permanent Investment</td>
</tr>
<tr>
<td>Cost of Land: 2.00% of Total Depreciable Capital</td>
</tr>
<tr>
<td>Cost of Royalties: $0</td>
</tr>
<tr>
<td>Cost of Plant Start-Up: 10.00% of Total Depreciable Capital</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operations</strong></td>
</tr>
<tr>
<td>Operators per Shift: 1 (assuming 5 shifts)</td>
</tr>
<tr>
<td>Direct Wages and Benefits: $40 /operator hour</td>
</tr>
<tr>
<td>Direct Salaries and Benefits: 15% of Direct Wages and Benefits</td>
</tr>
<tr>
<td>Operating Supplies and Services: 6% of Direct Wages and Benefits</td>
</tr>
<tr>
<td>Technical Assistance to Manufacturing: $50,000.00 per year, for each Operator per Shift</td>
</tr>
<tr>
<td>Control Laboratory: $55,000.00 per year, for each Operator per Shift</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
</tr>
<tr>
<td>Wages and Benefits: 4.50% of Total Depreciable Capital</td>
</tr>
<tr>
<td>Salaries and Benefits: 25% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td>Materials and Services: 100% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td>Maintenance Overhead: 5% of Maintenance Wages and Benefits</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Plant Overhead: 7.10% of Maintenance and Operations Wages and Benefits</td>
</tr>
<tr>
<td>Mechanical Department Services: 2.40% of Maintenance and Operations Wages and Benefits</td>
</tr>
<tr>
<td>Employee Relations Department: 5.90% of Maintenance and Operations Wages and Benefits</td>
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<td>Business Services: 7.40% of Maintenance and Operations Wages and Benefits</td>
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<table>
<thead>
<tr>
<th>Property Taxes and Insurance</th>
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<tbody>
<tr>
<td>Property Taxes and Insurance: 2% of Total Depreciable Capital</td>
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<table>
<thead>
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<th>Straight Line Depreciation</th>
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<tr>
<td>Direct Plant: 8.00% of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities</td>
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<tr>
<td>Allocated Plant: 6.00% of 1.18 times the Allocated Costs for Utility Plants and Related Facilities</td>
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<table>
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<th>Other Annual Expenses</th>
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<td>Licensing Fees: $0</td>
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<td>Miscellaneous: $0</td>
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## Cash Flow Summary

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<th>Sales</th>
<th>Capital Costs</th>
<th>Working Capital</th>
<th>Year Costs</th>
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<th>Depreciation</th>
<th>Abnormality</th>
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<th>Taxes</th>
<th>Net Earnings</th>
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<td>$0</td>
<td>($35,141,000)</td>
</tr>
</tbody>
</table>
Table 7 contains the results of the profitability analysis of this project at current market conditions. For capital investment accounting purposes, a five year MACRS depreciation schedule was chosen. The profitability analysis was conducted assuming one year of construction time and three years to ramp up to full production. Equipment costs were reported using estimates from Seider, et. al, 2009. The estimates for variable cost include the raw materials, utilities, and general expenses necessary for production. The fixed cost estimates include operations, maintenance, operating overhead, taxes, and depreciation. Although the best effort was made to minimize variable and fixed costs, we acknowledge that there is always room for improvement in the plant design and these costs may be able to be reduced further.

This project is highly sensitive to crude prices and the margin between propane and propene. The IRR of this project as a function of the price of propene in shown below in Figure 8.
Sensitivity analysis were also conducted to analyze the effect of changes in total permanent investment, variable costs, and fixed costs on overall profitability. These results are presented in Table 8 below. Using these analyses, it is possible to determine that even if the alternative methods of C3 separation were used, the project is not financially feasible under current economic conditions.

At current market prices, this design is not expected to be profitable due to a negative IRR and an NPV of $857,000,000. However, economic feasibility depends on volatile market conditions. Market research shows that propene prices will remain depressed over the next few years due to increased on-purpose production coming online and softer demand. In positive news, however, the price of propane is also expected to remain depressed. As the following table shows, the price of propene has to rise above $0.43 for this process to make economic sense. Fortunately, the price of propane is not highly correlated with the price of propene, making the possibility of this price gap rise possible. As recent as 2015, prices of propene hovered around $0.50 which would allow for an IRR of 11% at our current variable costs. Market analysis has
shown that other companies have already taken advantage of this opportunity in the past few years, shifting the market dramatically. This project may make sense in the long term as reduced production of propene from steam cracker and refineries will drive up prices.
<table>
<thead>
<tr>
<th>Product Price</th>
<th>Fixed Costs</th>
<th>Variable Costs</th>
<th>Total Permanent Investment</th>
</tr>
</thead>
<tbody>
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<td>$192,510.027</td>
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<td>-1.0%</td>
<td>-2.0%</td>
<td>-1.0%</td>
</tr>
</tbody>
</table>

Table 8: Expected IRR as a function of Fixed Costs, Variable Costs, and Total Permanent Investment.
Conclusion

The design and profitability analysis for the process to manufacture 700 kT/year of polymer grade propene from propane oxydehydrogenation has been presented. The reduction in propene supplies from steam cracker and refineries, in combination with the resulting higher price levels, are supporting investment in on-purpose production. However, market analysis has shown that other companies have already taken advantage of this opportunity in the past 3 years, shifting the market dramatically. Under current economic conditions, the project has an estimated NPV of -$865MM and a negative IRR. This project may make economic sense if a rebound in the price of propene is expected in the future.

The largest factor affecting the degree of profitability for this project is the margin between propane and propene. Due to the recent large investments in PDH plants by companies around the world, the market is unattractive to producers in the short term. Currently, plants are producing at 70% capacity to avoid flooding the market with propene. However, potential increases in the price of propene may make this design economical, especially considering a plant life of 20 years.

In addition to improving the propane/propene price margin, another way to improve the feasibility of this project is to decrease capital and operating costs. The capital costs are very large for this project due to the high temperatures at which the reactors are run and the need for excess capacity for regeneration. While there is room for improvement, this design is still within a factor of 2 of the cost of similar plants built in the Philadelphia area. Discussions with industry sources have also indicated that the UOP process is more economical that the STAR by Thyssen Krupp process that this design uses.
Acknowledgments

We would like to thank Dr. Raymond Gorte and Professor Leonard Fabiano for their continued support, advice, and guidance throughout the semester as we progressed through the various stages of our design project.

We would like to thank all of the industrial consultants: Mr. Gary Sawyer of Process Evaluations, Mr. David Kolesar of the Dow Chemical Company, Dr. Ivan Baldychev of Air Products and Chemicals, Mr. Bruce Vrana of DuPont Research and Technology, and Mr. Steven Tieri of DuPont Research and Technology, who all took the time to meet with us during our weekly group meetings. Their insight and expertise greatly assisted in the development of our design project.

Additionally, we would like to acknowledge Mr. John Wismer, the project author, who passed away November 8, 2015.
Bibliography


The Udhe STAR Process – Oxydehydrogenation of light paraffins to olefins – Promotional Brochure available at Thyssen Krupp Website.


Appendix A: Sample Calculations

Reactor Calculations

\[ m_{\text{catalyst}} = \text{catalyst loading weight (lb)} \]
\[ m_{\text{propane}} = \text{propane feed flowrate (lb/hr)} \]
\[ \text{WHSV} = \text{weighted hourly space velocity (hr}^{-1}) \]
\[ V_R = \text{reactor volume (ft}^3) \]
\[ \rho_{\text{bulk}} = \text{bulk density of packed bed (lb/ft}^3) \]
\[ \rho_{\text{particle}} = \text{density of catalyst particle (lb/ft}^3) \]
\[ \epsilon = \text{void fraction} \]
\[ \tau = \text{residence time (hr)} \]
\[ Q = \text{Volumetric flowrate (ft}^3/\text{hr}) \]
\[ D_i = \text{inner tube diameter (ft)} \]
\[ k = \text{thermal conductivity of packed bed (Btu/hr}^\circ\text{F} \cdot \text{ft}) \]
\[ h = \text{convective heat transfer of air (Btu/hr}^\circ\text{F} \cdot \text{ft}^2) \]
\[ Bi = \text{Biot number, Bi < 0.1 for zero temperature gradient} \]
\[ L = \text{tube length (ft)} \]
\[ N = \text{number of tubes} \]
\[ t_{sp} = \text{wall thickness (ft)} \]
\[ P_d = \text{design pressure (psia)} \]
\[ S = \text{maximum allowable stress of shell material (psia)} \]
\[ E = \text{fractional weld efficiency} \]
\[ \rho_m = \text{material density (lb/ft}^3) \]
\[ W = \text{vessel weight (lb)} \]
\[ v_s = \text{superficial velocity (ft/s)} \]
\[ D_p = \text{particle diameter (in)} \]
\[ \phi = \text{thiele modulus} \]
\[ r = \text{reaction rate (psia/s)} \]
\[ D_c = \text{diffusion rate (psia/s)} \]
\[ \Delta p = \text{pressure drop (psia/s)} \]
\[ \mu = \text{dynamic viscosity of fluid (lb/ft/hr)} \]
\[ \rho_f = \text{density of fluid} \left( \frac{lb}{ft^3} \right) \]

\[ m_{\text{catalyst}} = \frac{m_{\text{propane}}}{\text{WHSV}} \]

\[ V_R = \frac{m_{\text{catalyst}}}{\rho_{\text{bulk}}} \]

\[ \tau = \frac{V_R}{Q} \]

\[ \epsilon = 1 - \frac{\rho_{\text{bulk}}}{\rho_{\text{particle}}} \]

\[ D_i = \frac{kBi}{h} \]

\[ N = \frac{V_R}{D_i^2 L} \]

\[ t_{sp} = \frac{P_d D_i}{2SE - 1.2P_d} \]

\[ W = \pi(D_i + t_{sp})(L + 0.8D_i)t_{sp} \rho_m \]

\[ v_s = \frac{Q}{\pi D_i^2} \]

\[ \phi = \frac{r}{D_c} \]

\[ \Delta p = \frac{150 \mu L (1 - \epsilon)^2}{D_p^2} v_s + \frac{1.75L \rho_f (1 - \epsilon)}{D_p} \epsilon^3 v_s |v_s| \]

**Adsorption Column Calculations Procedure and Considerations**

1. Determine the content of the component(s) that are to be removed from the process stream in question. If a reactor with solid/bed catalyst obviously this is not pertinent.

2. Find a suitable adsorbent and the likely "loading" that is applicable. That is how many pounds of the component per 100 pounds of adsorbent are applicable. This is from supplier's data or literature data to be confirmed by a supplier.
3. Typical “CYCLE TIMES” for a system in which the component content is essentially constant or near constant are 8, 12 or 24 hours. That is the CYCLE represents the total time period from the moment the bed goes “on stream” to the time it has been regenerated and is ready to “go on stream” again.

The selection of the cycle times is such that it may more likely end and start with a “shift change” of operators. Now the 12-hour cycle would not meet that criterion but would mean that it is to be completed every day at the same time by whatever crew is on shift!

4. In the case where the process stream impurities are not known and/or are not constant; or are at a very low concentration and the cycle might be for a month or more. Example: oftentimes a product stream contains a detectable impurity and it must be removed, but its actual chemical structure is not known, the application of activated carbon is used to remove it. The applicability of the activated carbon would have been determined by experimental work. In this case it is often the norm to include only one such bed and the contents (activated carbon) are replaced rather than regenerated.

5. Having determined the amount to be removed per hour and the loading and selecting a cycle time we can size the bed; i.e., calculate the pounds/volume of adsorbent required.

6. An L/D of 3/1 is a good rule of thumb for the dimensions of the bed holding vessel. Allow for the volume of the “heads” of the vessel to be filled with “ceramic balls” to assist in distribution of the process gas both at the inlet and the outlet. So, only the “straight height” of the vessel will be filled with absorbent.

7. Remember that the higher the pressure the greater the wall thickness of the vessel will be. This criterion may influence your L/D choice as the smaller the diameter the smaller the wall thickness (and the price of the vessel in general).

8. As a rule two beds are placed in service. One is on stream while the other is regenerated and made ready to go on stream. A sketch will be sent separately from this note.

9. Normally the “heat of adsorption” is not sufficient to raise the bed temperature significantly. However, it should be looked at to be certain. The heat of adsorption is not normally available and one can use the heat of condensation (latent heat) as an approximation. If there is a significant heating effect one should consider cooling the inlet gas to account for the heating of the bed to attempt to hold it isothermal.

10. Next one must calculate the “total heat content” of the bed; vessel and associated piping and valves to determine how much heat must be added to the bed and associated equipment to reach the “required regeneration temperature”. For driers and carbon/molecular sieve adsorbers a temperature of 300 degrees F is sufficient. Driers and molecular sieve adsorbers can be operated at 100 degrees F and oftentimes they are operated at 40 degrees F to increase their adsorptive capacity significantly. The trade-off between the smaller bed and associated equipment is the higher cost of the refrigeration load to cool the bed back down to 40 degrees F.

Remember the heat content of the vessel and piping and valves must be included. The vessels will be insulated to reduce heat losses and the insulation content can be ignored.
11. For a rough estimate at the early stage of a design at which time the piping and valves have not been selected/designed lets simply use a factor of 1.25 times the bed and vessel heat content as the total heat load.

12. Now let’s look at the process sketch while a description of the events take place:
   · The newly regenerated bed will be brought on stream by “cracking open” the inlet valve to pressurize the bed.
   · When the operating pressure is reached the outlet valve will be opened slowly such that the process stream is now distributing between the “old bed” and the “new bed”.
   · Next the outlet valve of the old bed is slowly closed until all the flow is passing through the new bed.
   · The inlet to the old bed is closed.
   · Now the old and new beds are isolated from each other and the regeneration process can take place.
   · The old bed will be at the operating pressure and must be relieved to near atmospheric pressure.
   · The disposal or recovery of the relieving gases is to be considered in your design. It cannot as a rule be relieved to the atmosphere and if it is toxic it must receive special consideration.

13. Next the regeneration begins:
   · There is an external recirculation loop that contains a recirculation blower, a heater, a cooler if the component to be removed is water or a material that can be readily condensed and sent to treatment, a “knock-out pot” (simply a vessel to separate vapor from liquid), pressure control systems (two) to relieve the system as the system heats up and the gases in the “closed loop” expand and would raise the loop pressure if not relieved and the other to allow an inert gas to enter the loop during the cooling cycle to prevent the loop pressure from falling due to a contraction of the gases as the system cools.
   · Steam, hot oil or an electric heater can supply the heat to the recirculation system if the high temperature is not available via the other media. The inlet temperature to the bed will be 350 degrees F as a rule but must be verified with the supplier and for the specific application.
   · The gas used in the loop can be one of several choices and depending on the bed composition and the material that is being desorbed. The gas could be whatever gas is the process gas; nitrogen (provided as make-up only and not once through) and some cases could be air if the oxygen content would not cause a deterioration or safety hazard.
   · The bed is at T operating, say 100 Degrees F. and the hot gas enters at 350 Degrees F. As a simplifying assumption and by the way this works out quite reasonably one will assume that the hot gas is cooled to the bed temperature, 100 Degrees F in this case, as it exits the bed; this will be the case for one half of the heat up period. By the way the total regeneration cycle is 8 or 12 hours most likely and one must allow 1 hour for switching valves, depressurization and other tasks for the transition. So as a for instance assume that the cycle is 8 hours then there is 7 hours for the heating and cooling of the bed and the one hour for switching, depressurization and repressurization.
   · For the second half of the heating period (as of yet not specified beyond 7 hours for heating and cooling) one assumes that the temperature out of the bed is a “straight line” between 100 Degrees F and 300 Degrees F. Or that on average during the second half of the heating period the hot gas exits the bed at the average temperature or 200 Degrees F. Remember for a solid bed the temperature profile will be quite flat until the bed heats up along its length and along the way the
exit temperature will begin to rise. Detailed dynamic calculations would show that the shape of the exit case temperature curve with time would be exponential in shape. Perhaps the upswing half of a parabola would describe it better.

- Given these pieces of information; the heat load, the temperature profile of the exit heated gas and the heat capacity of the regeneration (heated gas) the “total flow” of the regeneration (heated gas) can be calculated. This does not answer how long the heating period will be; that will be computed later!
- Next we compute the cooling load required to bring the bed and associated equipment back to operating temperature, in this example 100 Degrees F.
- Now the flow in the regeneration loop is valved so that the blower output goes through the cooler and not the heater so that gas the supply to the bed is 100 Degrees F. In general, the flow to the beds is in the downward direction so that the bed will not be subjected to a “lift” during normal flow and regeneration.
- During cooling the same criteria are applied to the temperatures leaving the bed; during the first half of the cooling cycle the temperature of the exit gas is the same as the bed (350 degrees F); during the second half the temperature is the average of 350 and 100 degrees F or 225 degrees F. From the cooling load, the gas heat capacity and the delta T’s the amount of gas required can be calculated.
- Now the total amount of regeneration gas required for both the heating and the cooling periods is known by the simple summation of the two. Remember that in this case the total time for regeneration is 8 – 1 = 7 hours. Therefore, the gas flow rate will be the total gas calculated divided by 7 hours. For blower design this should be converted to actual cubic feet per minute.
- Now the actual duration of the heating and cooling periods is simply the ratio between the total gas required and the fraction of gas for cooling or heating which must add up to 1 times the 7 hours.

14. OTHER CONCERNS:
- The blower will heat up the recirculation gas and will then contribute to the heating requirements. Don’t ignore this.
- The cooler is used in the suction of the blower to condense out water if present. Otherwise if the regeneration gas is removing carbon dioxide or some other gas that does not condense then the cooler is not needed if the blower capacity can be such that the hot gas return can be directly added to the blower suction. Remember that the blower capacity is greatly reduced if the inlet temperature (and hence the volume is increased lowering the capacity of the blower) is increased.
- When removing “other” gases and not water, the recycle loop gases need to be purged at “some rate” to be certain that the adsorbed component is desorbed. Judgment is required here.

Catalyst Burn Regeneration Calculations

Objective

1) Describe a method for removal of hydrocarbon or carbon residue that deposits on catalyst during normal operation

2) This is done via controlled temperature and oxygen content of “burn-off” vapor circulation.
Issues of concern:
1) Maximum temperature allowed for catalyst during regeneration
2) Maximum amount of hydrocarbon (carbon) build up allowed between regenerations
3) Lower explosive limit (lel) for oxygen in “burn gas” if applicable
4) What is the maximum temperature of the bed/contents be allowed?
5) What temperature of the “burn gas” will be selected for the “burn”?
6) What temperature will the bed/contents be cooled to before placing
7) What composition of the recirculation gas?

Calculations:
1) Research the lel for oxygen in burn gas mixture if applicable and select a level of 50% of lel or less. This will be moderated by the maximum temperature in bed allowed.
2) The burn cycle will start by purging the vessels and piping with nitrogen to avoid explosive mixtures
3) Start burn with appropriate oxygen % and use cooled combustion gas as carrier gas.
4) Select the burn gas inlet temperature based on maximum desired temperature in the bed.
5) Calculate the the exit temperature of the burn gas as: for one half the time the exit gas of the reactor will be approximated as the cold end of the reactor assuming that for an endothermic reaction this is significantly colder than the inlet end of the bed.
6) If the entire bed is at the same temperature use it.
7) For the second half of the burn cycle use the burn temperature as the outlet of the recirculating gas.
8) Use the average of these two temperature values as the approximate for the average temperature of the recirculation gas for the burn gas.
9) The exit combustion/recirculation gas must be cooled to the desired colder temperature and recirculated to the reactor
10) Calculate the q value to cool the weight of the vessel (multiply that by 1.5 to include the piping and valves); the catalyst bed; and the insulation. Then calculate the q to be removed from the operating temperature to say 300 f in this case.
11) Now you can decide how long the burn cycle will take to burn all of the carbon off the catalyst. You have decided how long you will operate the reactor and the carbon build
up. Given the lbs of carbon you can calculate the amount of oxygen that you need at the “safe” oxygen

12) Concentration to burn it off. Pick the time for burn and then you can simply calculate the flow rate of burn gas required to remove all of the carbon.

13) Using the weights calculating above of the vessel and etc. Calculate the \( q \) to be removed for the cool-down. Using the average temperatures for cooling described above, pick a time and with the \( q \) and time desired you can calculate the flow rate for cooling required.

Remember now that during the burn cycle and the cooling cycle there is a need to cool the recirculation gas before it returns to the reactor. Also, there is a need to purge or add to the recirculation gas during burn and cooling.

**Membrane Calculations**

\[
\text{PermA} = \frac{F_p \cdot Y_a}{A \cdot \Delta P_a}
\]

\[
\Delta P_a = \frac{P_f \cdot Z_a - X_a \cdot P_r}{\ln \frac{P_f \cdot Z_a}{X_a \cdot P_r}}
\]

\[
F_p = \frac{\text{PermA} \cdot Y_a \cdot \frac{P_f \cdot Z_a - P_r \cdot X_a}{\ln \frac{P_f \cdot Z_a}{P_r \cdot X_a}} - Y_a \cdot P_p}{\ln \frac{P_f \cdot Z_a}{P_r \cdot X_a}}
\]

\[
F_p = \frac{\text{PermA} \cdot P_f \cdot (1 - Z_a) - P_r \cdot (1 - X_a)}{\ln \frac{P_f \cdot (1 - Z_a)}{P_r \cdot (1 - X_a)}} - (1 - Y_a) \cdot P_p
\]

\[
F_r = \frac{(Z_a - Y_a) \cdot F_f}{X_a - Y_a}
\]

\[
\text{Area} = \frac{Y_a \cdot F_p}{\left( \frac{P_f \cdot Z_a - X_a \cdot P_r}{P_f \cdot Z_a - Y_a \cdot P_p} \right) \cdot \text{PermA}}
\]

\( F_f \) = Feed Flow
\( F_p \) = Permeate flow
\( F_r \) = Retentate flow
$Y_a = \text{Permeate Propylene comp}$
$X_a = \text{Retentate Propylene comp}$
$Z_a = \text{Feed Propylene comp}$
$P_p = \text{Permeate pressure}$
$P_r = \text{Retentate Pressure}$
$P_f = \text{Feed Pressure}$
$S = \text{Selectivity}$
$\text{Perm}A = \text{Permeability propylene}$
$\text{Perm}B = \text{Permeability propane}$

**Pump Calculations**

$W = 7.27 \times 10^{-5} \times F \times \Delta P$

$W = \text{work (HP)}$

$F = \text{volumetric flowrate (ft}^3/\text{hr})$

$\Delta P = \text{pressure change (psia)}$

$H = \frac{\Delta P}{\rho_L}$

$H = \text{head (ft)}$

$\rho_L = \text{liquid’s density (lb/ft}^3)$

**Heat Exchanger Calculations**

$Q = UA\Delta T_{LM} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{cl})}{\ln \frac{(T_{hi} - T_{co})}{(T_{ho} - T_{cl})}}$

$Q = \text{duty of the exchanger (BTU/hr)}$

$U = \text{heat exchanger transfer coefficient (BTU/hr/ft/F)}$

$A = \text{Surface area of the exchanger (ft}^2)$

$T_{hi} = \text{inlet temperature of hot stream (R)}$

$T_{ho} = \text{outlet temperature of hot stream (R)}$

$T_{cl} = \text{inlet temperature of cold stream (R)}$

$T_{co} = \text{outlet temperature of cold stream (R)}$

**Reflux Accumulator Calculations**

$F = (1+R) (D_{\text{volumetric}})$

$\text{Volume} = 2*F*\tau$

$\text{Assume L}/D=2$

$D = \left(\frac{2V}{\pi}\right)^{\frac{1}{3}}$

$F = \text{volumetric flow rate (ft}^3/\text{hr)}$

$D_{\text{volumetric}} = \text{distillate flow rate (ft}^3/\text{hr)}$

$R = \text{reflux ratio}$

$L = \text{length of drum (ft)}$

$D = \text{diameter of drum (ft)}$

$\tau = \text{residence time (hr)}$
Distillation Column Calculations

\[ U_f = C_{SB} F_{ST} F_F F_{HA} \left( \frac{\rho_L - \rho_V}{\rho_V} \right)^{\frac{1}{2}} \]

\[ F_{ST} = \left( \frac{\sigma}{20} \right)^{\frac{1}{5}} \]

\[ F_{LG} = \frac{L}{V} \left( \frac{\rho_V}{\rho_L} \right)^{\frac{1}{2}} \]

\[ U = 0.85 \times U_f \]

\[ D = \left( \frac{4V}{9\pi \rho_V U} \right)^{\frac{1}{2}} \]

\[ H = HeadSpace + \left( N_{Trays} - 1 \right) \times TraySpacing + SumpSpace \]

\( U_f \) = flooding velocity (ft/s)
\( C_{SB} \) = flooding correlation
\( F_{ST} \) = surface tension
\( \sigma \) = surface tension of liquid (dyne/cm)
\( F_F \) = foaming factor
\( F_{HA} \) = hole area factor
\( \rho_V \) = density of the vapor phase (lb/ft\(^3\))
\( \rho_L \) = density of the liquid phase (lb/ft\(^3\))
\( L \) = liquid volumetric flow rate (ft\(^3\)/s)
\( V \) = vapor volumetric flow rate (ft\(^3\)/s)
\( D \) = diameter (ft)
Appendix B: Aspen Plus Input Summary, Block Report and Stream Report

Flowsheet
DYNAMICS
DYNAMICS RESULTS=ON
IN-UNITS ENG
DEF-STREAMS CONVEN ALL
MODEL=OPTION
DATABANKS 'APV88 PURE32' / 'APV88 AQUEOUS' / 'APV88 SOLIDS' / &
'APV88 INORGANIC' / 'APEOSV88 AP-EOS' / NOASPENPCD
PROP-SOURCES 'APV88 PURE32' / 'APV88 AQUEOUS' / 'APV88 SOLIDS' &
'APV88 INORGANIC' / 'APEOSV88 AP-EOS'
COMPONENTS
PROPANE C3H8 /
PROPENE C3H6=2 /
HYDROGEN H2 /
OXYGEN O2 /
WATER H2O /
CO CO /
CO2 CO2 /
METHANE CH4 /
ETHANE C2H6 /
ETHENE C2H4
SOLVE
RUN-MODE MODE=SIM
FLOWSHEET
BLOCK HX101 IN=s110 s105 OUT=s111 s15
BLOCK Mx101 IN=s102 s9 s16 OUT=s104
BLOCK Mx102 IN=s104 s103 s14 OUT=s105
BLOCK C202 IN=s206 OUT=s207
BLOCK C201 IN=s205 OUT=s206
BLOCK AD201 IN=s114 OUT=s203 s202
BLOCK MEA201 IN=s203 OUT=s204 s205
BLOCK DC201 IN=s207 OUT=3 s301
BLOCK H103 IN=s122 OUT=s114 s1
BLOCK T101 IN=s111 OUT=s112
BLOCK H302 IN=s315 OUT=s316
BLOCK HX001 IN=s309 s304 OUT=s315 s305
BLOCK C303 IN=s308 OUT=s309
BLOCK C302 IN=s307 OUT=s308
BLOCK H301 IN=s305 OUT=s306
BLOCK P301 IN=s303 OUT=s304
BLOCK DC301 IN=s301 OUT=s303 s102
BLOCK M301 IN=s306 OUT=s307 s310
BLOCK Mx301 IN=s311 s4 OUT=s312
BLOCK C304 IN=s313 OUT=s314
BLOCK H303 IN=RECY OUT=s313
BLOCK C301 IN=s310 OUT=s311
BLOCK Mx101 IN=s101 s116 OUT=s102
BLOCK B1 IN=s312 OUT=RECY PURGE
BLOCK SP101 IN=s1 OUT=s3 2
BLOCK P101 IN=2 OUT=S116
BLOCK R101 IN=S15 OUT=S108
BLOCK R102 IN=S108 S109 OUT=1 S2
BLOCK B6 IN=S302 OUT=S4
BLOCK H000 IN=1 S2 OUT=S110
BLOCK B2 IN=3 PURGE S7 OUT=S6 S8
BLOCK B3 IN=S8 OUT=S9 S10 S11 S12 S13 S14

PROPERTIES UNIQUAC

DEF-STREAMS CONVEN S102 2 1 3
PROP-SET PS-1 TEMP PRES HFLMX UNITS='F' 'psia' 'Btu/hr' &
SUBSTREAM=MIXED

STREAM 3
SUBSTREAM MIXED TEMP=70. PRES=14.7
MOLE-FLOW OXYGEN 7000.

STREAM S7
SUBSTREAM MIXED TEMP=70. PRES=14.7
MOLE-FLOW OXYGEN 7000.

STREAM S101
SUBSTREAM MIXED TEMP=77.00000000 PRES=72.51886887
MOLE-FLOW WATER 1873.929229

STREAM S103
SUBSTREAM MIXED TEMP=77.00000000 PRES=72.51886887
MOLE-FLOW PROPANE 4883.239107

STREAM S104
SUBSTREAM MIXED TEMP=1094.000000 PRES=72.51886887
MOLE-FLOW WATER 9592.313028

STREAM S105
SUBSTREAM MIXED TEMP=470.6569292 PRES=72.51886887
MOLE-FLOW PROPANE 5594.987588 / PROPENE .012479756 / &
WATER 9595.203795

STREAM S109
SUBSTREAM MIXED TEMP=1094.000000 PRES=73.00000000
MOLE-FLOW OXYGEN 750.0000000

STREAM S110
SUBSTREAM MIXED TEMP=1094.000000 PRES=72.51886887
MOLE-FLOW PROPANE 2732.000000 / PROPENE 2798.874593 / &
HYDROGEN 1726.233812 / OXYGEN 45.14412842 / WATER &
10792.15506 / CO 50.15846695 / CO2 50.00799176 / &
METHANE 30.77442683 / ETHANE 9.2323070 / ETHENE &
21.54209882

STREAM S111
SUBSTREAM MIXED TEMP=570.0383492 PRES=72.51886887
MOLE-FLOW PROPANE 2732.000000 / PROPENE 2798.874593 / &
HYDROGEN 1726.233812 / OXYGEN 45.14412842 / WATER &
10792.15506 / CO 50.15846695 / CO2 50.00799176 / &
METHANE 30.77442683 / ETHANE 9.2323070 / ETHENE &
21.54209882

STREAM S112
SUBSTREAM MIXED TEMP=457.3765616 PRES=34.80905705
MOLE-FLOW PROPANE 2390.492724 / PROPENE 2449.015269 / &

Page 2
STREAM 114
SUBSTREAM MIXED TEMP=176.00000000 PRES=34.80905705
MOLE-FLOW PROPANE 751.089003 / PROPANE 1.137834025 /
HYDROGEN 2993.952830 / WATER 14411.37866 / CO &
68.20321581 / CO2 46.09549429 / METHANE 43.86554116 / &
ETHANE 14.34564435 / ETHENE 31.13185524

STREAM S116
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW PROPANE 365.979897 / PROPANE 111.8283377 / &
HYDROGEN 0.5746443619 / OXYGEN 0.1697640051 / WATER &
9361.705820 / CO 0.1415510488 / CO2 1.651896446 / &
METHANE 2072380544 / ETHANE 3083234697 / ETHENE &
0.618458728

STREAM S202
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW WATER 77.35835349 / CO 43.74710756 / CO2 &
42.10509626 / METHANE 0.2672388556 / ETHANE 0.0769796357 / &
ETHENE 18.28749062

STREAM S203
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW PROPANE 2024.512890 / PROPANE 2137.196845 / &
HYDROGEN 1509.879873 / OXYGEN 39.33135582 / WATER &
4.071492031 / METHANE 26.45516083 / ETHANE 7.620983704

STREAM S204
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW HYDROGEN 1.509879873 / WATER 1.180732690

STREAM S205
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW PROPANE 2024.512890 / PROPANE 2137.196845 / &
HYDROGEN 1508.369993 / OXYGEN 39.33135582 / WATER &
2.890759340 / METHANE 26.45516083 / ETHANE 7.620983704

STREAM S206
SUBSTREAM MIXED TEMP=166.7917980 PRES=78.00000000
MOLE-FLOW PROPANE 2024.512890 / PROPANE 2137.196845 / &
HYDROGEN 1508.369993 / OXYGEN 39.33135582 / WATER &
2.890759340 / METHANE 26.45516083 / ETHANE 7.620983704

STREAM S207
SUBSTREAM MIXED TEMP=296.0887764 PRES=250.00000000
MOLE-FLOW PROPANE 2024.512890 / PROPANE 2137.196845 / &
HYDROGEN 1508.369993 / OXYGEN 39.33135582 / WATER &
2.890759340 / METHANE 26.45516083 / ETHANE 7.620983704

STREAM S301
SUBSTREAM MIXED TEMP=112.3483237 PRES=241.98000000
MOLE-FLOW PROPANE 2010.661171 / PROPANE 1744.186738 / &
HYDROGEN 5.94247871E-6 / OXYGEN 1.74824656E-4 / WATER &
2.890759340 / METHANE 7.26307830E-4 / ETHANE &
0.668081146

STREAM S303
SUBSTREAM MIXED TEMP=106.20000000 PRES=225.00000000
DEF-STREAMS HEAT S13
DEF-STREAMS HEAT S14
DEF-STREAMS HEAT S16

STREAM S16
INFO HEAT DUTY=165000000.

BLOCK MX101 MIXER
PARAM

BLOCK MX102 MIXER
PARAM

BLOCK MX301 MIXER
PARAM

BLOCK B1 FSPTRIT
FRAC RECY 0.9

BLOCK B3 FSPTRIT
DUTY S10 5$006618.9 / S11 220341562. / S12 54314968. / &
S13 13345144.9 / S14 161962246.

BLOCK SP101 FSPTRIT
FRAC S3 0.1

BLOCK AD201 SEP
PARAM
FRAC STREAM=202 SUBSTREAM=MIXED COMPS=PROPANE PROPENE &
HYDROGEN OXYGEN WATER CO CO2 METHANE ETHANE ETHENE &
FRAC=0.0 0.0 0.95 0. 0.01 0.01 0.0.

BLOCK M301 SEP
PARAM
MOLE-FLOW STREAM=S307 SUBSTREAM=MIXED COMPS=PROPANE &
PROPENE FLOWS=21.03801465 4186.978359

BLOCK MEA201 SEP
PARAM
FRAC STREAM=204 SUBSTREAM=MIXED COMPS=PROPANE PROPENE &
HYDROGEN OXYGEN WATER CO CO2 METHANE ETHANE ETHENE &
FRAC=0.0 0.001 0.29 0.94 0. 0. 0.

BLOCK H000 HEATER
PARAM PRES=525 DPPARMOPT=NO

BLOCK H101 HEATER
PARAM PRES=72.51886887 NPHASE=2 DPPARMOPT=NO
BLOCK-OPTION FREE-WATER=NO

BLOCK H103 HEATER
PARAM TEMP=176.0000000 PRES=34.80901705 DPPARMOPT=NO
BLOCK-OPTION FREE-WATER=NO

BLOCK H301 HEATER
PARAM TEMP=257.0000000 PRES=375.0000000 DPPARMOPT=NO

BLOCK H302 HEATER
PARAM TEMP=100.0000000 PRES=250.0000000 DPPARMOPT=NO
BLOCK H303 HEATER
PARAM TEMP=71.6,00000000 PRES=20.00000000 DPPARMOPT=NO

BLOCK HX104 HEATX
PARAM T=COLD=1094, PRES=HOT=52.5,00000000 MIN-TAPP=18.00000000
FEEDS HOT=5115 COLD=5105
OUTLETS-HOT 5115 OUTLETS-COLD 5105
HOT-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
COLD-SIDE DP-OPTION=NO
TQ-PARAM CURVE=NO

BLOCK HX301 HEATX
PARAM DUTY=1000000, CALC-TYPE=DESIGN MIN-TAPP=7.000000000 &
U-OPTION=PHASE F-OPTION=CONSTANT CALC-METHOD=SHORTCUT
FEEDS HOT=5309 COLD=5304
OUTLETS-HOT 5315 OUTLETS-COLD 5305
HOT-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
COLD-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
TQ-PARAM CURVE=NO

BLOCK DC201 RADDRAC
PARAM NSTAGE=20 ALGORITHM=STANDARD MAXOL=100 DAMPING=NONE
COL-CONFIG CONDENSER=PARTIAL V
FEEDS 5207 19
PRODUCTS 5301 20 L / 3 1 V
P-SPEC 1 270.00000000
COL-SPECS DP-STAGE=.1100000000 MOLE-D=3472.280629 MOLE-RR=4.5 &
DP-COND=10.000000000
TRAY-SIZE 1 2 19 FLEXI NPASS=4

BLOCK DC301 RADDRAC
PARAM NSTAGE=90 ALGORITHM=STANDARD MAXOL=25 DAMPING=NONE
COL-CONFIG CONDENSER=TOTAL
FEEDS 5303 45
PRODUCTS 5301 1 L / 5302 90 L
P-SPEC 1 225.00000000
COL-SPECS DP-STAGE=.1100000000 MOLE-D=6613.867866 MOLE-RR=5. &
DP-COND=10.000000000
TRAY-SIZE 1 2 89 FLEXI NPASS=4

BLOCK B2 RSTOIC
PARAM TEMP=1094.0, PRES=14.7 COMBUSTION=YES PROD-NOX=NO

BLOCK R101 RSTOIC
PARAM TEMP=1094.0,00000000 PRES=73.000000000 SERIES=YES
STOIC 1 MIXED PROPANE -1. / PROPANE 1. / HYDROGEN 1.
STOIC 2 MIXED PROPANE -1. / METHANE 1. / ETHANE 1.
STOIC 3 MIXED ETHANE -1. / HYDROGEN -1. / ETHANE 1.
CONV 1 MIXED PROPANE 0.313
CONV 2 MIXED PROPANE 0.002
CONV 3 MIXED ETHANE 0.3

BLOCK R102 RSTOIC
PARAM TEMP=1094.0,00000000 PRES=56.300000000 SERIES=YES
STOIC 1 MIXED PROPA 1. / PROPANE 1. / HYDROGEN 1.
STOIC 2 MIXED PROPA -1. / ETHANE 1. / METHANE 1.
STOIC 3 MIXED PROPA -1. / OXYGEN -5. / CO2 3. / &
WATER 4.
STOIC 4 MIXED PROPA -1. / OXYGEN -3.5 / CO 3. / &
WATER 4.
STOIC 5 MIXED ETHANE -1. / HYDROGEN -1. / ETHANE 1.
STOIC 6 MIXED HYDROGEN -1 / OXYGEN -0.5 / WATER 1.
CONV 1 MIXED PROPANE 0.22375
CONV 2 MIXED PROPANE 0.0011
CONV 3 MIXED PROPANE 0.008
CONV 4 MIXED PROPANE 0.004
CONV 5 MIXED ETHENE 0.3
EXTENT 6 983.9230761

BLOCK B6 PUMP
PARAM PRES=20.00000000 PUMP-TYPE=TURBINE

BLOCK P101 PUMP
PARAM PRES=72.51886887

BLOCK P301 PUMP
PARAM PRES=575.0000000

BLOCK C201 COMPR
PARAM TYPE=ISENTROPIC PRES=100.00000000 SB-MAXIT=30 & SB-TOL=0.0001

BLOCK C202 COMPR
PARAM TYPE=ISENTROPIC PRES=300.00000000 SB-MAXIT=30 & SB-TOL=0.0001

BLOCK C301 COMPR
PARAM TYPE=ISENTROPIC PRES=20.00000000 NPHASE=2 SB-MAXIT=30 & SB-TOL=0.0001 MODEL-TYPE=TURBINE
BLOCK-OPTION FREE-WATER=NO

BLOCK C302 COMPR
PARAM TYPE=ISENTROPIC PRES=20.00000000 NPHASE=2 SB-MAXIT=30 & SB-TOL=0.0001 MODEL-TYPE=TURBINE
BLOCK-OPTION FREE-WATER=NO

BLOCK C303 COMPR
PARAM TYPE=ISENTROPIC PRES=250.00000000 SB-MAXIT=30 & SB-TOL=0.0001 MODEL-TYPE=COMPRESSOR

BLOCK C304 COMPR
PARAM TYPE=ISENTROPIC PRES=72.51886887 NPHASE=1 SB-MAXIT=30 & SB-TOL=0.0001 MODEL-TYPE=COMPRESSOR
BLOCK-OPTION FREE-WATER=NO

BLOCK T101 COMPR
PARAM TYPE=ISENTROPIC PRES=34.80905705 SB-MAXIT=30 & SB-TOL=0.0001 MODEL-TYPE=TURBINE

EO-CONV-OPTI

CONV-OPTIONS
PARAM TOL=0.1


REATIONS R-1 GENERAL
REAC-DATA 1 NAME=OHYGROQ REAC-CLASS=POWERLAW PHASE=V & DELT=1080.000000 CBASIS=PARTIALPRES RBASIS=CAT-WT & PRES-UNIT="BAR"
REAC-DATA 3 NAME=SPLH PHASE=V CBASIS=PARTIALPRES & RBASIS=CAT-WT PRES-UNIT="BAR"
REAC-DATA 5 NAME=HYDROG REAC-CLASS=POWERLAW STATUS=ON
RATE-CON 1 PRE-EXP=0.015 ACT-ENERGY=25795.35684
RATE-CON 2 PRE-EXP=1E-005 ACT-ENERGY=17196.90456
RATE-CON 5 PRE-EXP=2E-005 ACT-ENERGY=21496.13069
STOIC 1 MIXED PROPANE -1. / HYDROGEN 1. / PROPENE 1.
STOIC 3 MIXED PROPANE -1. / METHANE 1. / ETHENE 1.
STOIC 5 MIXED ETHENE -1. / HYDROGEN -1. / ETHANE 1.
REAC-ACT 1 / $
~AP6AG0.tmp

**Block Report**

**Block:** AD201  **Model:** SEP

**Inlet Streams:** S114  
**Outlet Streams:** S203  S202  
**Property Option Set:** UNIQUAC  UNIQUAC / IDEAL GAS

---

### Mass and Energy Balance

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Balance</td>
<td>13621.6</td>
<td>13621.6</td>
<td>-0.534147E-15</td>
</tr>
<tr>
<td>Flow (lbmol/hr)</td>
<td>43391.8</td>
<td>43391.8</td>
<td>-0.536578E-15</td>
</tr>
<tr>
<td>Enthalpy (BTU/hr)</td>
<td>-0.244816E+09</td>
<td>-0.255166E+09</td>
<td>0.405609E-01</td>
</tr>
</tbody>
</table>

---

### CO2 Equivalent Summary

- Feed streams CO2E: 12430.4 lb/hr
- Product streams CO2E: 12430.4 lb/hr
- Net streams CO2E Production: 0.00000 lb/hr
- Utilities CO2E Production: 0.00000 lb/hr
- Total CO2E Production: 0.00000 lb/hr

---

### Input Data

**Flash Spec for Stream S203**
- Two Phase TP Flash
- Pressure drop: 0.0 psi
- Maximum no. iterations: 30
- Convergence tolerance: 0.00010000

**Flash Spec for Stream S202**
- Two Phase TP Flash
- Pressure drop: 0.0 psi
- Maximum no. iterations: 30
- Convergence tolerance: 0.00010000

**Fraction of Feed**

<table>
<thead>
<tr>
<th>Substream= Mixed</th>
<th>CPT= Propane</th>
<th>Fraction= 0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Propene</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Hydrogen</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Oxygen</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>0.0</td>
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<tr>
<td></td>
<td>CO</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>CO2</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Ethane</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Ethene</td>
<td>0.0</td>
</tr>
</tbody>
</table>

---

### Results

- Heat Duty: -0.10350E+08 BTU/hr

**Component = Propene**

- Stream S202 Mixed Split Fraction 1.00000

**Component = Propene**

- Stream S203 Mixed Split Fraction 1.00000

**Component = Hydrogen**

---

Page 1
STREAM	SUBSTREAM	SPLIT FRACTION
S203	MIXED	1.00000

COMPONENT = WATER
STREAM	SUBSTREAM	SPLIT FRACTION
S203	MIXED	0.050000
S202	MIXED	0.950000

COMPONENT = CO
STREAM	SUBSTREAM	SPLIT FRACTION
S203	MIXED	1.000000

COMPONENT = CO2
STREAM	SUBSTREAM	SPLIT FRACTION
S203	MIXED	1.000000

COMPONENT = METHANE
STREAM	SUBSTREAM	SPLIT FRACTION
S203	MIXED	0.990000
S202	MIXED	0.010000

COMPONENT = ETHANE
STREAM	SUBSTREAM	SPLIT FRACTION
S203	MIXED	0.990000
S202	MIXED	0.010000

COMPONENT = ETHENE
STREAM	SUBSTREAM	SPLIT FRACTION
S203	MIXED	1.000000

BLOCK: B1	MODEL: FSPLIT
---------------------------------------------------------------------
INLET STREAM:	S312
OUTLET STREAMS:	RECY	PURGE
PROPERTY OPTION SET:	UNIQUAC	UNIQUAC / IDEAL GAS
**** MASS AND ENERGY BALANCE ****

IN	OUT	RELATIVE DIFF.

TOTAL BALANCE:
MOLE(LBMOL/HR)	5240.37	5240.37	0.00000
MASS(LB/HR)	229716.	229716.	0.00000
ENTHALPY(BTU/HR)	-0.227995E+09	-0.227995E+09	0.00000

**** CO2 EQUIVALENT SUMMARY ****

FEED STREAMS CO2E:
3.30868	LB/HR

PRODUCT STREAMS CO2E:
3.30868	LB/HR

NET STREAMS CO2E PRODUCTION:
0.00000	LB/HR

UTILITIES CO2E PRODUCTION:
0.00000	LB/HR

TOTAL CO2 PRODUCTION:
0.00000	LB/HR

**** INPUT DATA ****

FRACTION OF FLOW:
STRM=RECY	FRAC=0.90000

**** RESULTS ****

STREAM= RECY	SPLIT=0.90000	KEY=0
PURGE=0.100000	STREAM-ORDER=1

BLOCK: B2	MODEL: RSTOIC
---------------------------------------------------------------------
INLET STREAMS:	3
OUTLET STREAM:	S6	PURGE	S7
OUTLET HEAT STREAM:  S8
PROPERTY OPTION SET:  UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***
IN   OUT   GENERATION   RELATIVE DIFF.
MOLE (LB/HR )  1096.3    9840.55   -1155.77   0.165418E-15
MASS (LB/HR )  258604.    258604.  0.00000
ENTHALPY (BTU/HR ) -0.315200E+08  -0.315200E+08  -0.472752E-15

*** CO2 EQUIVALENT SUMMARY ***
FEED STREAMS CO2E  7484.40  LB/HR
PRODUCT STREAMS CO2E  81040.3  LB/HR
NET STREAMS CO2E PRODUCTION  73555.9  LB/HR
UTILITIES CO2E PRODUCTION  0.00000  LB/HR
TOTAL CO2E PRODUCTION  73555.9  LB/HR

*** INPUT DATA ***
TWO PHASE TP FLASH  1,094.00
SPECIFIED TEMPERATURE F  14.7000
SPECIFIED PRESSURE PSIA  30
MAXIMUM NO. ITERATIONS  0.000100000
CONVERGENCE TOLERANCE
SIMULTANEOUS REACTIONS
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES  YES
COMBUSTION PRODUCT FOR CHEMICALLY BOUND NITROGEN NO

*** RESULTS ***
OUTLET TEMPERATURE F  1094.0
OUTLET PRESSURE PSIA  14.700
HEAT DUTY BTU/HR  -0.774411E+09
VAPOR FRACTION  1.0000

COMBUSTION REACTIONS:

RXN NO  STOICHIOMETRY
C1  PROPANE + 5 OXYGEN --> 4 WATER + 3 CO2
C2  PROPENE + 4.5 OXYGEN --> 3 WATER + 3 CO2
C3  HYDROGEN + 0.5 OXYGEN --> WATER
C4  0.5 OXYGEN + CO --> CO2
C5  2 OXYGEN + METHANE --> 2 WATER + CO2
C6  3.5 OXYGEN + ETHANE --> 3 WATER + 2 CO2
C7  3 OXYGEN + ETHENE --> 2 WATER + 2 CO2

REACTION EXTENTS:

<table>
<thead>
<tr>
<th>REACTION NUMBER</th>
<th>REACTION EXTENT</th>
<th>LB/HR</th>
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<tr>
<td>C1</td>
<td>483.58</td>
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</tr>
<tr>
<td>C2</td>
<td>90.471</td>
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</tr>
<tr>
<td>C3</td>
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<tr>
<td>C4</td>
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<tr>
<td>C5</td>
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<td>C6</td>
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<td>C7</td>
<td>9.9568</td>
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V-L PHASE EQUILIBRIUM:

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<th>X(I)</th>
<th>Y(I)</th>
<th>K(I)</th>
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<td>OXYGEN</td>
<td>0.24314</td>
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<td>WATER</td>
<td>0.56674</td>
<td>0.88044</td>
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<td>CO2</td>
<td>0.18713</td>
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**BLOCK: B3, MODEL: FSPLIT**

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<tr>
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<th>S9</th>
<th>S10</th>
<th>S11</th>
<th>S12</th>
<th>S13</th>
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<tbody>
<tr>
<td>OUTLET STREAM</td>
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<td></td>
<td></td>
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<td></td>
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</table>

**PROPERTY OPTION SET: UNIQUAC / IDEAL GAS**

**TOTAL BALANCE**

| ENTHALPY (BTU/HR) | 0.774410E+09 | 0.774410E+09 | 0.00000 |

**RESULTS**

<table>
<thead>
<tr>
<th>STREAM</th>
<th>S9</th>
<th>S10</th>
<th>S11</th>
<th>S12</th>
<th>S13</th>
<th>S14</th>
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</thead>
<tbody>
<tr>
<td>SPLIT</td>
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<td>0.068448</td>
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**BLOCK: B6, MODEL: PUMP**

<table>
<thead>
<tr>
<th>INLET STREAM</th>
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<tr>
<td>OUTLET STREAM</td>
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**PROPERTY OPTION SET: UNIQUAC / IDEAL GAS**

**TOTAL BALANCE**

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<th>NOле (LB/HR)</th>
<th>2834.12</th>
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<td>MASS (LB/HR)</td>
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<tr>
<td>ENTHALPY (BTU/HR)</td>
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<td>0.934831E-03</td>
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</tbody>
</table>

**CO2 EQUIVALENT SUMMARY**

| FEED STREAMS CO2E | 0.00000 | LB/HR |
| PRODUCT STREAMS CO2E | 0.00000 | LB/HR |
| NET STREAMS CO2E PRODUCT | 0.00000 | LB/HR |
| UTILITIES CO2E PRODUCT | 0.00000 | LB/HR |

**INPUT DATA**

| EQUIPMENT TYPE: TURBINE |
| OUTLET PRESSURE PSIA | 20.0000 |
| DRIVER EFFICIENCY | 1.00000 |

**FLASH SPECIFICATIONS:**

| LIQUID PHASE CALCULATION | NO PLASH PERFORMED |
| MAXIMUM NUMBER OF ITERATIONS | 30 |
| TOLERANCE | 0.00010000 |

**RESULTS**

| VOLUMETRIC FLOW RATE CUFT/HR | 4.416.56 |
| PRESSURE CHANGE PSI | -224.680 |
BLOCK: C201 MODEL: COMPR

INLET STREAM: S205
OUTLET STREAM: S206
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE (LB/MOL/HR)</td>
<td>12920.3</td>
<td>12920.3</td>
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</tr>
<tr>
<td>MASS (LB/HR)</td>
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<td>0.00000</td>
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<tr>
<td>ENTHALPY (BTU/HR)</td>
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<td>-0.140095E+09</td>
<td>-0.154101</td>
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</tbody>
</table>

*** CO2 EQUIVALENT SUMMARY ***

- FEED STREAMS CO2E: 7487.38 LB/HR
- PRODUCT STREAMS CO2E: 7487.38 LB/HR
- NET STREAMS CO2E PRODUCTION: 0.000000 LB/HR
- UTILITIES CO2E PRODUCTION: 0.000000 LB/HR
- TOTAL CO2E PRODUCTION: 0.000000 LB/HR

*** INPUT DATA ***

- ISENTROPIC CENTRIFUGAL COMPRESSOR
- OUTLET PRESSURE PSIA: 100.000
- ISENTROPIC EFFICIENCY: 0.72000
- MECHANICAL EFFICIENCY: 1.00000

*** RESULTS ***

- INDICATED HORSEPOWER REQUIREMENT HP: 10,030.4
- BRAKE HORSEPOWER REQUIREMENT HP: 10,030.4
- NET WORK REQUIRED HP: 10,030.4
- POWER LOSSES HP: 0.0
- ISENTROPIC HORSEPOWER REQUIREMENT HP: 7,221.88
- CALCULATED OUTLET TEMP F: 294.195
- ISENTROPIC TEMPERATURE F: 262.506
- EFFICIENCY (POLYTR/ISENTR) USED: 0.72000
- OUTLET VAPOR FRACTION: 1.00000
- HEAD DEVELOPED FT-LBF/LB: 34,171.5
- MECHANICAL EFFICIENCY USED: 1.00000
- INLET HEAT CAPACITY RATIO: 1.24507
- INLET VOLUMETRIC FLOW RATE, CFU/HR: 2,532,020
- OUTLET VOLUMETRIC FLOW RATE, CFU/HR: 1,045,250
- INLET COMPRESSIBILITY FACTOR: 1.00000
- OUTLET COMPRESSIBILITY FACTOR: 1.00000
- AV. ISENT. VOL. EXPONENT: 1.13753
- AV. ISENT. TEMP EXPONENT: 1.13753
- AV. ACTUAL VOL. EXPONENT: 1.19275
- AV. ACTUAL TEMP EXPONENT: 1.19275

BLOCK: C202 MODEL: COMPR

INLET STREAM: S206
OUTLET STREAM: S207
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS
~AP6A60.tmp

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE (LB/MOL/HR)</td>
<td>12920.3</td>
<td>12920.3</td>
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<tr>
<td>MASS (LB/HR)</td>
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<td>41845.8</td>
<td>0.000000</td>
</tr>
<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.140095E+09</td>
<td>-0.108743E+09</td>
<td>-0.223788</td>
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</table>

*** CO2 EQUIVALENT SUMMARY ***

| FEED STREAMS CO2E | 7487.38 | LB/HR |
| PRODUCT STREAMS CO2E | 7487.38 | LB/HR |
| NET STREAMS CO2E PRODUCTION | 0.000000 | LB/HR |
| UTILITIES CO2E PRODUCTION | 0.000000 | LB/HR |
| TOTAL CO2 PRODUCTION | 0.000000 | LB/HR |

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

OUTLET PRESSURE PSIA | 300.000 |
ISENTROPIC EFFICIENCY | 0.72000 |
MECHANICAL EFFICIENCY | 1.00000 |

*** RESULTS ***

| INDICATED HORSEPOWER REQUIREMENT | 12,321.7 |
| BRAKE HORSEPOWER REQUIREMENT | 12,321.7 |
| NET WORK REQUIRED | 12,321.7 |
| POWER LOSSES | 0.0 |
| ISENTROPIC HORSEPOWER REQUIREMENT | 8,871.59 |
| CALCULATED OUTLET TEMP F | 423.422 |
| ISENTROPIC TEMPERATURE F | 388.640 |
| EFFICIENCY (POLYTR/ISENTR) USED | 0.72000 |
| OUTLET VAPOR FRACTION | 1.00000 |
| HEAD DEVELOPED, FT-LBF/LB | 41,977.3 |
| MECHANICAL EFFICIENCY USED | 1.00000 |
| INLET HEAT CAPACITY RATIO | 1.12635 |
| INLET VOLUMETRIC FLOW RATE, CUFT/HR | 1,045,250 |
| OUTLET VOLUMETRIC FLOW RATE, CUFT/HR | 408,144 |
| INLET COMPRESSIBILITY FACTOR | 1.00000 |
| OUTLET COMPRESSIBILITY FACTOR | 1.00000 |
| AV. ISENT. VOL. EXPONENT | 1.12037 |
| AV. ISENT. TEMP EXPONENT | 1.12037 |
| AV. ACTUAL VOL. EXPONENT | 1.16824 |
| AV. ACTUAL TEMP EXPONENT | 1.16824 |

BLOCK: C301 MODEL: COMPR

---

INLET STREAM: S310
OUTLET STREAM: S311
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
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<th>OUT</th>
<th>RELATIVE DIFF.</th>
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</thead>
<tbody>
<tr>
<td>MOLE (LB/MOL/HR)</td>
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<tr>
<td>MASS (LB/HR)</td>
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<tr>
<td>ENTHALPY (BTU/HR)</td>
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<td>0.813621E-01</td>
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</table>

*** CO2 EQUIVALENT SUMMARY ***

| FEED STREAMS CO2E | 3.30868 | LB/HR |
| PRODUCT STREAMS CO2E | 3.30868 | LB/HR |
| NET STREAMS CO2E PRODUCTION | 0.000000 | LB/HR |
| UTILITIES CO2E PRODUCTION | 0.000000 | LB/HR |

Page 6
TOTAL CO2E PRODUCTION 0.00000  LB/HR

*** INPUT DATA ***

ISENTEROPIC TURBINE
OUTLET PRESSURE PSIA 20.0000
ISENTEROPIC EFFICIENCY 0.72000
MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP -2,765.41
BRAKE HORSEPOWER REQUIREMENT HP -2,765.41
NET WORK REQUIRED HP -2,765.41
POWER LOSSES HP 0.0
ISENTEROPIC HORSEPOWER REQUIREMENT HP -3,840.84
CALCULATED OUTLET TEMP F 109.977
ISENTEROPIC TEMPERATURE F 44.1026
EFFICIENCY (POLYTR/ISENTR) USED 0.72000
OUTLET VAPOR FRACTION 1.00000
HEAD DEVELOPED, FT-LBF/LB -72,202.6
MECHANICAL EFFICIENCY USED 1.00000
INLET HEAT CAPACITY RATIO 1.10048
INLET VOLUMETRIC FLOW RATE, CUFT/HR 32,184.7
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR 735,485
INLET COMRESSIBILITY FACTOR 1.00000
OUTLET COMRESSIBILITY FACTOR 1.00000
AV. ISEN. VOL. EXPONENT 1.11726
AV. ISEN. TEMP EXPONENT 1.11726
AV. ACTUAL VOL. EXPONENT 1.07338
AV. ACTUAL TEMP EXPONENT 1.07338

BLOCK: C302  MODEL: COMP

INLET STREAM: S307
OUTLET STREAM: S308
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL BALANCE</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MOLE(LB/MOL/HR)</td>
<td>4207.62</td>
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<tr>
<td>ENTHALPY(BTU/HR )</td>
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</table>

*** CO2E 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 ***

ISENTEROPIC TURBINE
OUTLET PRESSURE PSIA 20.0000
ISENTEROPIC EFFICIENCY 0.72000
MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP -4,732.51
BRAKE HORSEPOWER REQUIREMENT HP -4,732.51

Page 7
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Net Work Required HP</td>
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<td>Outlet Vapor Fraction</td>
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<tr>
<td>Head Developed FT-Lbf/Lb</td>
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<td>Mechanical Efficiency Used</td>
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<tr>
<td>Inlet Heat Capacity Ratio</td>
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<td>Inlet Volumetric Flow Rate, Cft/Hr</td>
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<tr>
<td>Outlet Volumetric Flow Rate, Cft/Hr</td>
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<td>Inlet Compressibility Factor</td>
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<tr>
<td>Outlet Compressibility Factor</td>
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<td>Av. Actual Temp Exponent</td>
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**Block:** c303  **Model:** COMPR

---

**Inlet Stream:** S308  **Outlet Stream:** S309

**Property Option Set:** UNIQUEAC UNIQUEAC / IDEAL GAS

*** Mass and Energy Balance ***

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
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<tbody>
<tr>
<td>Mole (lbmol/hr)</td>
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<tr>
<td>Mass (lb/hr)</td>
<td>177102.</td>
<td>177102.</td>
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<tr>
<td>Enthalpy (BTU/hr)</td>
<td>0.356561E+08</td>
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*** CO2 Equivalent Summary ***

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<tbody>
<tr>
<td>Feed Streams CO2</td>
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<td>LB/HR</td>
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<tr>
<td>Product Streams CO2</td>
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<td>LB/HR</td>
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<tr>
<td>Net Streams CO2</td>
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<td>LB/HR</td>
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<tr>
<td>Utilities CO2</td>
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<td>LB/HR</td>
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<tr>
<td>Total CO2 Production</td>
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<td>LB/HR</td>
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</table>

*** Input Data ***

Isentropic Centrifugal Compressor

Outlet Pressure PSIA 250.000

Isentropic Efficiency 0.72000

Mechanical Efficiency 1.00000

*** Results ***

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
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<td>Indicated Horsepower Requirement HP</td>
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<td>Brake Horsepower Requirement HP</td>
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<tr>
<td>Power Losses HP</td>
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<td>Isentropic Horsepower Requirement HP</td>
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<td>Calculated Outlet Temp F</td>
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<td>Isentropic Temperature F</td>
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<td>Efficiency (Polytropic) Used</td>
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<tr>
<td>Outlet Vapor Fraction</td>
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<tr>
<td>Head Developed, FT-Lbf/Lb</td>
<td>59,652.3</td>
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<tr>
<td>Mechanical Efficiency Used</td>
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<tr>
<td>Inlet Volumetric Flow Rate, Cft/Hr</td>
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<tr>
<td>Outlet Volumetric Flow Rate, Cft/Hr</td>
<td>144,119.</td>
</tr>
<tr>
<td>Inlet Compressibility Factor</td>
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</table>
OUTLET COMPRESSIBILITY FACTOR 1.00000
AV. ISENT. VOL. EXPONENT 1.12700
AV. ISENT. TEMP EXPONENT 1.12700
AV. ACTUAL VOL. EXPONENT 1.16949
AV. ACTUAL TEMP EXPONENT 1.16949

BLOCK: C304  MODEL: COMPR

---

INLET STREAM: S313
OUTLET STREAM: S314
PROPERTY OPTION SET: UNIQAC UNIQAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

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*** CO2 EQUIVALENT SUMMARY ***

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*** INPUT DATA ***

GAS PHASE CALCULATION
NO FLASH PERFORMED

ISENTRPIC CENTRIFUGAL COMPRESSOR
OUTLET PRESSURE PSIA 72.5189
ISENTRPIC EFFICIENCY 0.72000
MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

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BLOCK: DC201  MODEL: RADFRAC

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INLETS - S207 STAGE 19
OUTLETS - 3 STAGE 1
S301 STAGE 20

Page 9
PROPERTY OPTION SET: UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

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*** CO2 EQUIVALENT SUMMARY ***

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<td>NET STREAMS CO2E PRODUCTION</td>
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***** INPUT DATA *****

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**** INPUT PARAMETERS ****

NUMBER OF STAGES   20
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 100
MAXIMUM NO. OF INSIDE LOOP ITERATIONS 10
MAXIMUM NUMBER OF FLASH ITERATIONS 30
FLASH TOLERANCE 0.00010000
OUTSIDE LOOP CONVERGENCE TOLERANCE 0.00010000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST 1.00000
MOLAR REFLUX RATIO 4.50000
MOLAR DISTILLATE RATE LBMOL/HR 3,472.28

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 270.000

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**** RESULTS ****

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*** COMPONENT SPLIT FRACTIONS ***

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Page 10
### SUMMARY OF KEY RESULTS

**TOP STAGE TEMPERATURE**

F = -96.1354

**BOTTOM STAGE TEMPERATURE**

F = 124.846

**TOP STAGE LIQUID FLOW**

LB/MOL/HR = 15,625.3

**BOTTOM STAGE LIQUID FLOW**

LB/MOL/HR = 9,447.99

**TOP STAGE VAPOR FLOW**

LB/MOL/HR = 3,472.28

**BOILUP VAPOR FLOW**

LB/MOL/HR = 10,557.1

**MOLAR REFLUX RATIO**

4.5000

**MOLAR BOILUP RATIO**

1.11739

**CONDENSER DUTY (W/O SUBCOOL)**

BTU/HR = -0.176457e+09

**REBOILER DUTY**

BTU/HR = 0.549858e+08

### MAXIMUM FINAL RELATIVE ERRORS

- **DEW POINT**
  - 0.31126e-13 STAGE= 2
- **BUBBLE POINT**
  - 0.12848e-10 STAGE= 2
- **COMPONENT MASS BALANCE**
  - 0.70224e-10 STAGE= 2 COMP=HYDROGEN
- **ENERGY BALANCE**
  - 0.54293e-11 STAGE= 1

### PROFILES

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

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<th>HEAT DUTY (BTU/HR)</th>
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### MASS FLOW PROFILES

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### HYDRAULIC PARAMETERS

---

### DEFINITIONS

**MARANGONI INDEX** = SIGMA - SIGMATO

**FLOW PARAM** = (ML/ MV)**SQT(RHOL/RHOL)

**QR** = MV**SQT(RHOL/RHOL)

**F FACTOR** = MV**SQT(RHOL)

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
RHOL IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV is the volumetric flow rate of vapor to the stage.

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***** TRAY SIZING CALCULATIONS *****

STARTING STAGE NUMBER 2
ENDING STAGE NUMBER 19
FLOODING CALCULATION METHOD

b960

DESIGN PARAMETERS

PEAK CAPACITY FACTOR 1.0000
SYSTEM FOAMING FACTOR 1.0000
FLOODING FACTOR 0.8000
MINIMUM COLUMN DIAMETER FT 1.0000
MINIMUM DC AREA/COLUMN AREA 0.1000

TRAY SPECIFICATIONS

TRAY TYPE FLEXI
NUMBER OF PASSES 4
TRAY SPACING FT 2.0000

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER 17
COLUMN DIAMETER FT 23.1168
DC AREA/COLUMN AREA 0.1000
SIDE DOWNCOMER VELOCITY FT/SEC 0.31087
FLOW PATH LENGTH FT 4.33799
SIDE DOWNCOMER WIDTH FT 1.40621
SIDE WEIR LENGTH FT 11.0507
CENTER DOWNCOMER WIDTH FT 0.90803
CENTER WEIR LENGTH FT 23.0990
OFF-CENTER DOWNCOMER WIDTH FT 1.02221
OFF-CENTER SHORT WEIR LENGTH FT 19.9792
OFF-CENTER LONG WEIR LENGTH FT 21.0365
TRAY CENTER TO ODC CENTER FT 5.30311

***** SIZING PROFILES *****

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BLOCK: DC301  MODEL: RADFRAC

INLETS  - S301  STAGE 45
OUTLETS  - S303  STAGE 1
S302  STAGE 90

Page 15
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

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*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 3.30868 LB/HR
PRODUCT STREAMS CO2E 3.30868 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 *****

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

**** INPUT PARAMETERS ****

NUMBER OF STAGES: 90
ALGORITHM OPTION: STANDARD
ABSORBER OPTION: NO
INITIALIZATION OPTION: STANDARD
HYDRAULIC PARAMETER CALCULATIONS: NO
INSIDE LOOP CONVERGENCE METHOD: BRODYEN
DESIGN SPECIFICATION METHOD: NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS: 25
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: 0.0
MOLAR REFLUX RATIO: 5.00000
MOLAR DISTILLATE RATE: LB/HR 6,613.67

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA: 225,000

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

**** RESULTS ****

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

**** COMPONENT SPLIT FRACTIONS ****

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CO2E COMPONENT:
PROPANE: 0.42156 0.57844
PROPENE: 0.99761 0.29000E-02
HYDROGEN: 1.0000 0.0000
WATER: 0.0000 1.0000
CO: 1.0000 0.0000

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### SUMMARY OF KEY RESULTS

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### MAXIMUM FINAL RELATIVE ERRORS

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### PROFILES

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

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**DEFINITIONS**

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FLOW PARAM = (ML/MV)^0.5 SQRT(RHOL/RHOL)
QR = QV^0.5 SQRT(RHOL/(RHOL-RHOL))
F FACTOR = QV^0.5 SQRT(RHOL)

WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMAT 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
RHOL IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

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**TRAY SIZING CALCULATIONS**

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*** SECTION 1 ***

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ENDING STAGE NUMBER: 89
FLOODING CALCULATION METHOD: 8960

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- 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

**TRAY SPECIFICATIONS**

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**SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER**

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INLET STREAM: 1
INLET HEAT STREAM: S2
OUTLET STREAM: S110
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

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*** MASS AND ENERGY BALANCE ***

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</tr>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
<td>-0.988521E-01</td>
<td>LB/HR</td>
<td></td>
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</table>

*** INPUT DATA ***

<table>
<thead>
<tr>
<th>TERMS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECIFIED PRESSURE PSIA</td>
<td>52.5000</td>
</tr>
<tr>
<td>DUTY FROM INLET HEAT STREAM BTU/HR</td>
<td>0.683458E+08</td>
</tr>
<tr>
<td>MAXIMUM NO. ITERATIONS</td>
<td>30</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
<td>0.00010000</td>
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*** RESULTS ***

<table>
<thead>
<tr>
<th>TERMS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE F</td>
<td>1210.7</td>
</tr>
<tr>
<td>OUTLET PRESSURE PSIA</td>
<td>52.500</td>
</tr>
<tr>
<td>OUTLET VAPOR FRACTION</td>
<td>1.0000</td>
</tr>
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</table>

V-L PHASE EQUILIBRIUM :

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>F(x)</th>
<th>X(x)</th>
<th>Y(x)</th>
<th>K(x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPANE</td>
<td>0.12586</td>
<td>0.16235E-02</td>
<td>0.13586</td>
<td>753.49</td>
</tr>
<tr>
<td>PROPENE</td>
<td>0.13063</td>
<td>0.13127E-02</td>
<td>0.13063</td>
<td>935.38</td>
</tr>
<tr>
<td>HYDROGEN</td>
<td>0.93162E-01</td>
<td>0.13769E-04</td>
<td>0.99162E-01</td>
<td>2627.1</td>
</tr>
<tr>
<td>WATER</td>
<td>0.63439</td>
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<td>623.37</td>
</tr>
<tr>
<td>CO</td>
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<td>1632.8</td>
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<td>CO2</td>
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<td>0.33015E-02</td>
<td>2353.9</td>
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<tr>
<td>METHANE</td>
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<td>0.50684E-03</td>
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<td>ETHANE</td>
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<td>0.10860E-05</td>
<td>0.23281E-03</td>
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<tr>
<td>ETHENE</td>
<td>0.28100E-03</td>
<td>0.91769E-06</td>
<td>0.28100E-03</td>
<td>1308.7</td>
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BLOCK: H101 MODEL: HEATER

INLET STREAM: S102
INLET HEAT STREAMS: S9 S16
OUTLET STREAM: S104
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th>TERMS</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE (LEMOl/HR)</td>
<td>21396.9</td>
<td>21396.9</td>
<td>0.00000</td>
</tr>
<tr>
<td>MASS (LB/HR)</td>
<td>385471</td>
<td>385471</td>
<td>0.00000</td>
</tr>
<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.215605E+10</td>
<td>-0.215605E+10</td>
<td>0.221162E-15</td>
</tr>
</tbody>
</table>

*** CO2 EQUIVALENT SUMMARY ***
FEED STREAMS CO2E  0.000000  LB/HR
PRODUCT STREAMS CO2E  0.000000  LB/HR
NET STREAMS CO2E PRODUCTION  0.000000  LB/HR
UTILITIES CO2E PRODUCTION  0.000000  LB/HR
TOTAL CO2 PRODUCTION  0.000000  LB/HR

*** INPUT DATA ***

TWO PHASE PQ FLASH
SPECIFIED PRESSURE  PSIA  72.5189
DUTY FROM INLET HEAT STREAM(S)  BTU/HR  0.438439E+09
MAXIMUM NO. ITERATIONS  30
CONVERGENCE TOLERANCE  0.00010000

*** RESULTS ***

OUTLET TEMPERATURE  F  466.70
OUTLET PRESSURE  PSIA  72.519
OUTLET VAPOUR FRACTION  1.0000

V-L PHASE EQUILIBRIUM :

COMP  F(i)  X(i)  Y(i)  K(i)
WATER  1.0000  1.0000  1.0000  6.8627

BLOCK:  H103  MODEL:  HEATER

INLET STREAM:  S112
OUTLET STREAM:  S114
OUTLET WATER STREAM:  S1
PROPERTY OPTION SET:  UNIQUAC  UNIQUAC / IDEAL GAS
FREE WATER OPTION SET:  SYSOP12  ASME STEAM TABLE
SOLUBLE WATER OPTION:  THE MAIN PROPERTY OPTION SET (UNIQUAC).

*** MASS AND ENERGY BALANCE ***

IN  OUT  RELATIVE DIFF.
TOTAL BALANCE
MOLE(LBMOL/HR)  35313.9  35313.9  0.0000
MASS(LB/HR )  824709.  824709.  0.282318E-15
ENTHALPY(BTU/HR ) -0.238191E+10 -0.238181E+10  0.170588

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E  12430.4  LB/HR
PRODUCT STREAMS CO2E  12430.4  LB/HR
NET STREAMS CO2E PRODUCTION  0.000000  LB/HR
UTILITIES CO2E PRODUCTION  0.000000  LB/HR
TOTAL CO2 PRODUCTION  0.000000  LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH
FREE WATER CONSIDERED
SPECIFIED TEMPERATURE  F  176.00
SPECIFIED PRESSURE  PSIA  34.8091
MAXIMUM NO. ITERATIONS  30
CONVERGENCE TOLERANCE  0.00010000

*** RESULTS ***

OUTLET TEMPERATURE  F  176.00
OUTLET PRESSURE  PSIA  34.809
HEAT DUTY BTU/HR ~AP6A60.tmp -0.48990E+09
OUTLET VAPOR FRACTION 0.38573
OUTLET: 1ST LIQUID/TOTAL LIQUID 0.0000

V-L1-L2 PHASE EQUILIBRIUM:

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<thead>
<tr>
<th>COMP</th>
<th>F(i)</th>
<th>X1(i)</th>
<th>X2(i)</th>
<th>Y(i)</th>
<th>K1(i)</th>
<th>K2(i)</th>
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<tr>
<td>PROPANE</td>
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<td>26.4</td>
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<tr>
<td>PROPENE</td>
<td>0.131</td>
<td>0.432E-01</td>
<td>0.00</td>
<td>0.340</td>
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<tr>
<td>HYDROGEN</td>
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<td>0.229E-03</td>
<td>0.00</td>
<td>0.244</td>
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<td>0.632</td>
<td>0.901</td>
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<td>0.235E-03</td>
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<td>ETHENE</td>
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<td>0.245E-04</td>
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**BLOCK: H301** **MODEL: HEATER**

**INLET STREAM:** S305 **OUTLET STREAM:** S306
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE (LBMOL/HR)</td>
<td>6613.87</td>
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<tr>
<td>MASS (LB/HR)</td>
<td>282428.</td>
<td>282428.</td>
<td>0.0000</td>
</tr>
<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.848981E+08</td>
<td>-0.305659E+08</td>
<td>-0.639969</td>
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</tbody>
</table>

*** CO2 EQUIVALENT SUMMARY ***

| FEED STREAMS CO2E | 3.30868 | LB/HR |
| PRODUCT STREAMS CO2E | 3.30868 | LB/HR |
| NET STREAMS CO2 PRODUCTION | 0.00000 | LB/HR |
| UTILITIES CO2 PRODUCTION | 0.00000 | LB/HR |
| TOTAL CO2 PRODUCTION | 0.00000 | LB/HR |

*** INPUT DATA ***

| TWO PHASE TP FLASH | F | 257.0 |
| SPECIFIED TEMPERATURE | PSIA | 575.0 |
| MAXIMUM NO. ITERATIONS | 30 |
| CONVERGENCE TOLERANCE | 0.0001 |

*** RESULTS ***

| OUTLET TEMPERATURE | F | 257.0 |
| OUTLET PRESSURE | PSIA | 575.0 |
| HEAT DUTY BTU/HR | 0.54332E+08 |
| OUTLET VAPOR FRACTION | 1.0000 |

V-L PHASE EQUILIBRIUM:

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(i)</th>
<th>X(i)</th>
<th>Y(i)</th>
<th>K(i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPANE</td>
<td>0.30871</td>
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<tr>
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<tr>
<td>HYDROGEN</td>
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<td>184.67</td>
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<td>37.190</td>
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</table>

Page 26
CO2: 0.86640E-05 0.86640E-05 8.3025
METHANE: 0.29661E-06 0.29661E-06 19.838
ETHANE: 0.31333E-04 0.31333E-04 5.0367
ETHENE: 0.10672E-04 0.10672E-04 7.1160

**BLOCK: H302 MODEL: HEATER**

INPUT STREAM: S315
OUTLET STREAM: S316
PROPERTY OPTION SET: UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE</td>
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<tr>
<td>MASS</td>
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<td>177102</td>
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</tr>
<tr>
<td>ENTHALPY</td>
<td>0.544198E+08</td>
<td>0.133028E+08</td>
<td>0.75553</td>
</tr>
</tbody>
</table>

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2: 0.00000 LB/HR
PRODUCT STREAMS CO2: 0.00000 LB/HR
NET STREAMS CO2 PRODUCTION: 0.00000 LB/HR
UTILITY CO2 PRODUCTION: 0.00000 LB/HR
TOTAL CO2 PRODUCTION: 0.00000 LB/HR

*** INPUT DATA ***

SPECFIED TEMPERATURE: 100.000
SPECIFIED PRESSURE: 250.000
MAXIMUM NO. ITERATIONS: 30
CONVERGENCE TOLERANCE: 0.000100000

*** RESULTS ***

OUTLET TEMPERATURE: 100.00
OUTLET PRESSURE: 250.00
HEAT DUTY: -0.41117E+08 BTU/HR
OUTLET VAPOR FRACTION: 0.0000

V-L PHASE EQUILIBRIUM:

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(x)</th>
<th>X(i)</th>
<th>Y(i)</th>
<th>K(i)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.41000E-02</td>
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<tr>
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<td>0.99500</td>
<td>0.99590</td>
<td>0.91745</td>
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</tbody>
</table>

**BLOCK: H303 MODEL: HEATER**

INPUT STREAM: RECY
OUTLET STREAM: S313
PROPERTY OPTION SET: UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE</td>
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<tr>
<td>MASS</td>
<td>206744</td>
<td>206744</td>
<td>0.00000</td>
</tr>
<tr>
<td>ENTHALPY</td>
<td>-0.205196E+09</td>
<td>-0.134699E+09</td>
<td>-0.511559E-01</td>
</tr>
</tbody>
</table>

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2: 2.97781 LB/HR

Page 27
PRODUCT STREAMS CO2  
2.97781  LB/HR

NET STREAMS CO2 PRODUCTION  
0.00000  LB/HR

UTILITIES CO2 PRODUCTION  
0.00000  LB/HR

TOTAL CO2 PRODUCTION  
0.00000  LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE  
F  71.6000

SPECIFIED PRESSURE  
PSIA  20.0000

MAXIMUM NO. ITERATIONS  
30

CONVERGENCE TOLERANCE  
0.000100000

*** RESULTS ***

OUTLET TEMPERATURE  
F  71.600

OUTLET PRESSURE  
PSIA  20.000

HEAT DUTY  
BTU/HR  0.10497E+08

OUTLET VAPOR FRACTION  
1.0000

V-L PHASE EQUILIBRIUM :

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(I)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>K(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPANE</td>
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<tr>
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<tr>
<td>WATER</td>
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<tr>
<td>CO</td>
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<td>0.56229E-09</td>
<td>0.10659E-06</td>
<td>609.67</td>
</tr>
<tr>
<td>CO2</td>
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<tr>
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<td>0.13469E-04</td>
<td>52.512</td>
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</tbody>
</table>

BLOCK: HX101  MODEL: HEATX

HOT SIDE:
INLET STREAM:  S110
OUTLET STREAM:  S111
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

COLD SIDE:

INLET STREAM:  S105
OUTLET STREAM:  S15
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

******************************************************************************
*                                                                
*  CALCULATED HOT SIDE FEED TEMPERATURE INCONSISTENT WITH INLET          *
******************************************************************************

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOL (LB/MOL/HR)</td>
<td>66310.4</td>
<td>66310.4</td>
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</tr>
<tr>
<td>MASS (LB/HR)</td>
<td>0.163226E+07</td>
<td>0.163226E+07</td>
<td>-0.142643E-15</td>
</tr>
<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.452923E+10</td>
<td>-0.452925E+10</td>
<td>0.421118E-15</td>
</tr>
</tbody>
</table>

Page 28
FEED STREAMS CO2
12433.3 LB/HR
PRODUCT STREAMS CO2
12433.3 LB/HR
NET STREAMS CO2 PRODUCTION
0.000000 LB/HR
UTILITIES CO2 PRODUCTION
0.000000 LB/HR
TOTAL CO2 PRODUCTION
0.000000 LB/HR

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

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

FLOW DIRECTION AND SPECIFICATION:
COUNTERCURRENT HEAT EXCHANGER
SPECIFIED COLD OUTLET TEMP
SPECIFIED VALUE F 1094.00000
LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:
HOT SIDE OUTLET PRESSURE PSI 52.5000
COLD SIDE PRESSURE DROP PSI 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
HOT LIQUID COLD LIQUID BTU/HR-SQFT-R 149.6937
HOT 2-PHASE COLD LIQUID BTU/HR-SQFT-R 149.6937
HOT LIQUID COLD LIQUID BTU/HR-SQFT-R 149.6937
HOT LIQUID COLD 2-PHASE BTU/HR-SQFT-R 149.6937
HOT 2-PHASE COLD 2-PHASE BTU/HR-SQFT-R 149.6937
HOT VAPOR COLD 2-PHASE BTU/HR-SQFT-R 149.6937
HOT LIQUID COLD VAPOR BTU/HR-SQFT-R 149.6937
HOT 2-PHASE COLD VAPOR BTU/HR-SQFT-R 149.6937
HOT VAPOR COLD VAPOR BTU/HR-SQFT-R 149.6937

STREAMS:

S110 -------> HOT -----< S111
t= 1.2107d+03
p= 5.2500d+01
v= 1.0000d+00

S15 <------ COLD <------ S105
t= 1.0940d+03
p= 7.2519d+01
v= 1.0000d+00

DUTY AND AREA:
CALCULATED HEAT DUTY BTU/HR 395114797.8539
CALCULATED (REQUIRED) AREA SQFT 18423.3719
ACTUAL EXCHANGER AREA SQFT 18423.3719
PER CENT OVER-DESIGN 0.0000

HEAT TRANSFER COEFFICIENT:
AVERAGE COEFFICIENT (DIRTY) ~AP6A60.tmp 149.6937
UA (DIRTY) BTU/HR-SQFT-R 2757861.9035

LOG-HEAT TEMPERATURE DIFFERENCE:
LMTD CORRECTION FACTOR 1.0000
LMTD (CORRECTED) F 143.2685
NUMBER OF SHELLS IN SERIES 1

PRESSURE DROP:
HOT SIDE, TOTAL PSI 0.0000
COLD SIDE, TOTAL PSI 0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

<table>
<thead>
<tr>
<th>HOT IN</th>
<th>VAP</th>
<th>HOT OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1210.7</td>
<td></td>
<td>460.8</td>
</tr>
<tr>
<td>COLD IN</td>
<td>VAP</td>
<td>COLD OUT</td>
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<tr>
<td>1094.0</td>
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<td>288.3</td>
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</table>

ZONE HEAT TRANSFER AND AREA:

<table>
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<tr>
<th>ZONE</th>
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<th>AREA SQFT</th>
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HEATX COLD-T QCU HX101 TQCURV INLET

PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

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**HEATX HOT-TCURV HX101 QCURV INLET**

**PROPERTY OPTION SET:** UNIQUAC
**PSI:** 0.0
**PRESSURE DROP:** 0.0 PSI
**PRESSURE PROFILE:** CONSTANT

**BLOCK:** HX301  **MODEL:** HEATX

**HOT SIDE:**

**INLET STREAM:** S309
**OUTLET STREAM:** S315

Page 31
PROPERTY OPTION SET:  UNIQUC   UNIQUC / IDEAL GAS
COLD SIDE:
-------------------
INLET STREAM:  s304
OUTLET STREAM: s305
PROPERTY OPTION SET:  UNIQUC   UNIQUC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

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*** CO2 EQUIVALENT SUMMARY ***

| FEED STREAMS CO2E | 3.30868 | LB/HR |
| PRODUCT STREAMS CO2E | 3.30868 | 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 EXCHANGER DUTY |
| SPECIFIED VALUE | BTU/HR | 1000000.0000 |
| LMTD CORRECTION FACTOR | 1.00000 |

PRESSURE SPECIFICATION:

| HOT SIDE PRESSURE DROP | PSI | 0.0000 |
| COLD SIDE PRESSURE DROP | PSI | 0.0000 |

HEAT TRANSFER COEFFICIENT SPECIFICATION:

| HOT LIQUID | COLD LIQUID | BTU/HR-SQFT-R | 149.6937 |
| HOT 2-PHASE | COLD LIQUID | BTU/HR-SQFT-R | 149.6937 |
| HOT LIQUID | COLD 2-PHASE | BTU/HR-SQFT-R | 149.6937 |
| HOT LIQUID | COLD VAPOR | BTU/HR-SQFT-R | 149.6937 |
| HOT 2-PHASE | COLD VAPOR | BTU/HR-SQFT-R | 149.6937 |
| HOT LIQUID | COLD VAPOR | BTU/HR-SQFT-R | 149.6937 |

*** OVERALL RESULTS ***

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<tr>
<td>P=</td>
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<tr>
<td>V=</td>
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DUTY AND AREA:
- Calculated Heat Duty: BTU/HR = 1000000.0000
- Calculated (required) Area: SQFT = 29.7354
- Actual Exchanger Area: SQFT = 29.7354
- Percent Over-Design: 0.0000

Heat Transfer Coefficient:
- Average Coefficient (Dirty): BTU/HR-SQFT-R = 149.6937
- Ua (Dirty): BTU/HR-R = 4451.1936

Log-Mean Temperature Difference:
- LMTD Correction Factor: 1.0000
- LMTD (Corrected): F = 224.6588
- Number of Shells in Series: 1

Pressure Drop:
- Hotside, Total: PSI = 0.0000
- Coldsidem, Total: PSI = 0.0000

*** ZONE RESULTS ***

Temperature Leaving Each Zone:

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| 105.9 ||

** Zone Heat Transfer and Area: **

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Heatx Cold-Tqcu Hx301 Tqcurv Inlet

| PRESSURE PROFILE: Constant2 |
| PRESSURE DROP: 0.0 PSI |
| PROPERTY OPTION SET: UNIQAC / UNIQAC / IDEAL GAS |

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| 2.8571e+05  | 575.0000 | 108.6178 | 0.0 |
| 3.3333e+05  | 575.0000 | 108.4408 | 0.0 |
| 3.8095e+05  | 575.0000 | 108.2636 | 0.0 |
| 4.2857e+05  | 575.0000 | 108.0862 | 0.0 |

| 4.7619e+05  | 575.0000 | 107.9087 | 0.0 |
| 5.2381e+05  | 575.0000 | 107.7311 | 0.0 |
| 5.7143e+05  | 575.0000 | 107.5533 | 0.0 |
| 6.1905e+05  | 575.0000 | 107.3754 | 0.0 |
| 6.6667e+05  | 575.0000 | 107.1973 | 0.0 |

| 7.1429e+05  | 575.0000 | 107.0190 | 0.0 |
| 7.6190e+05  | 575.0000 | 106.8406 | 0.0 |
| 8.0952e+05  | 575.0000 | 106.6621 | 0.0 |
| 8.5714e+05  | 575.0000 | 106.4834 | 0.0 |
| 9.0476e+05  | 575.0000 | 106.3046 | 0.0 |

HEATX HOT-QCURX HX301 TCURV INLET

PRESSURE PROFILE: CONSTANT
PRESSURE DROP: 0.0 PSI
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

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### CO2 Equivalent Summary

| **FEED STREAMS CO2E** | 3.30868 | **LB/HR** |
| **PRODUCT STREAMS CO2E** | 3.30868 | **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 Stream S307**
- **Two Phase TP Flash**
- **Pressure Drop** | PSI | 0.0 |
- **Maximum No. Iterations** | 30 |
- **Convergence Tolerance** | 0.000100000 |

**Flash Specs for Stream S310**
- **Two Phase TP Flash**
- **Pressure Drop** | PSI | 0.0 |
- **Maximum No. Iterations** | 30 |
- **Convergence Tolerance** | 0.000100000 |

**Mole-Flow (LBMOL/HR)**
- **Substream Mixed Stream S307**
- **CPT** = PROPANE
- **Flow** = 21.0380
- **PROPENE** = 4.186.58

### Results

**Heat Duty** | BTU/HR | -0.31778E-07 |

**Component = PROPANE**
- **Stream S307**
- **Substream Mixed** | 0.010304 |
- **S310**
- **Mixed** | 0.99970 |

**Component = PROPENE**
- **Stream S307**
- **Substream Mixed** | 0.901575 |
- **Mixed** | 0.084250 |

Page 35
COMPONENT = HYDROGEN  
STREAM     SUBSTREAM  SPLIT FRACTION  
s310  MIXED        1.00000  

COMPONENT = CO  
STREAM     SUBSTREAM  SPLIT FRACTION  
s310  MIXED        1.00000  

COMPONENT = CO2  
STREAM     SUBSTREAM  SPLIT FRACTION  
s310  MIXED        1.00000  

COMPONENT = METHANE  
STREAM     SUBSTREAM  SPLIT FRACTION  
s310  MIXED        1.00000  

COMPONENT = ETHANE  
STREAM     SUBSTREAM  SPLIT FRACTION  
s310  MIXED        1.00000  

COMPONENT = ETHENE  
STREAM     SUBSTREAM  SPLIT FRACTION  
s310  MIXED        1.00000  

BLOCK: MEA201  MODEL: SEP  
--------------------------------------  
INLET STREAM: S203  
OUTLET STREAMS: S204  S205  
PROPERTY OPTION SET: UNIQUAC  UNIQUAC / IDEAL GAS  

*** MASS AND ENERGY BALANCE ***  
IN          OUT          RELATIVE DIFF.  
TOTAL BALANCE  
  MOLE(LBMOL/HR)  13043.1  13043.1  -0.278920E-15  
  MASS(LB/HR)    423454.4  423494.  0.137446E-15  
  ENTHALPY( BTU/HR )  -0.185147E+09  -0.185147E+09  0.160966E-15  

*** CO2 EQUIVALENT SUMMARY ***  
FEED STREAMS CO2E  12357.9  LB/HR  
PRODUCT STREAMS CO2E  12357.9  LB/HR  
NET STREAMS CO2 PRODUCTION  0.00000  LB/HR  
UTILITIES CO2 PRODUCTION  0.00000  LB/HR  
TOTAL CO2 PRODUCTION  0.00000  LB/HR  

*** INPUT DATA ***  
FLASH SPECS FOR STREAM S204  
  TWO PHASE TP FLASH  
  PRESSURE DROP  PSI  0.0  
  MAXIMUM NO. ITERATIONS  30  
  CONVERGENCE TOLERANCE  0.000100000  
FLASH SPECS FOR STREAM S205  
  TWO PHASE TP FLASH  
  PRESSURE DROP  PSI  0.0  
  MAXIMUM NO. ITERATIONS  30  
  CONVERGENCE TOLERANCE  0.000100000  
FRACTION OF FEED  
  SUBSTREAM= MIXED  
  STREAM= S204  
  CPT= PROPANE  FRACTION= 0.0  
  PROPENE  FRACTION= 0.0  

Page 36
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<tr>
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<tr>
<td>ETHENE</td>
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### RESULTS

<table>
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<tr>
<th>COMPONENT</th>
<th>SUBSTREAM</th>
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<tr>
<td>PROPANE</td>
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<td>1.0000</td>
</tr>
<tr>
<td>ETHENE</td>
<td>S205</td>
<td>1.0000</td>
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**INLET STREAMS:**
S101  S116
**OUTLET STREAM:**
S102
**PROPERTY OPTION SET:**
UNIQUAC / IDEAL GAS

**MASS AND ENERGY BALANCE**

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
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</thead>
<tbody>
<tr>
<td>MOLE/(LBMOL/HR)</td>
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### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Feed Streams CO2e</th>
<th>0.000000 LB/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Streams CO2e</td>
<td>0.000000 LB/HR</td>
</tr>
<tr>
<td>Net Streams CO2e Production</td>
<td>0.000000 LB/HR</td>
</tr>
<tr>
<td>Utilities CO2e Production</td>
<td>0.000000 LB/HR</td>
</tr>
<tr>
<td>Total CO2e Production</td>
<td>0.000000 LB/HR</td>
</tr>
</tbody>
</table>

### INPUT DATA

- **Two Phase Flash**
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.000100000
- Outlet Pressure: Minimum of Inlet Stream Pressures

**Block: MX102 Model: MIXER**

<table>
<thead>
<tr>
<th>Inlet Streams:</th>
<th>S104</th>
<th>S103</th>
<th>S314</th>
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<tr>
<td>Outlet Stream:</td>
<td>S105</td>
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<tr>
<td>Property Option Set:</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mass and Energy Balance**

| Total Balance Mole(LBmol/HR) | 30996.5 | 30996.5 | -0.117367E-15 |
| Mass(LB/HR)                  | 807550. | 807550. | -0.103508E-08 |
| Enthalpy(BTU/HR)             | -0.256095E+10 | -0.256095E+10 | 0.947987E-08 |

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Feed Streams CO2e</th>
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</thead>
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<tr>
<td>Product Streams CO2e</td>
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</tr>
<tr>
<td>Net Streams CO2e Production</td>
<td>-0.351163E-06 LB/HR</td>
</tr>
<tr>
<td>Utilities CO2e Production</td>
<td>0.000000 LB/HR</td>
</tr>
<tr>
<td>Total CO2e Production</td>
<td>-0.351163E-06 LB/HR</td>
</tr>
</tbody>
</table>

### INPUT DATA

- **Two Phase Flash**
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.000100000
- Outlet Pressure: Minimum of Inlet Stream Pressures

**Block: MX301 Model: MIXER**

<table>
<thead>
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<th>S4</th>
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<tr>
<td>Outlet Stream:</td>
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<tr>
<td>Property Option Set:</td>
<td>UNIQUAC / IDEAL GASES</td>
<td></td>
</tr>
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</table>

**Mass and Energy Balance**

| Total Balance Mole(LBmol/HR) | 5240.37 | 5240.37 | 0.000000 |
| Mass(LB/HR)                  | 229716. | 229716. | -0.253390E-15 |
| Enthalpy(BTU/HR)             | -0.227995E+09 | -0.227995E+09 | 0.392144E-15 |

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Feed Streams CO2e</th>
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<tbody>
<tr>
<td>Product Streams CO2e</td>
<td>3.30868 LB/HR</td>
</tr>
<tr>
<td>Net Streams CO2e Production</td>
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</tr>
<tr>
<td>Utilities CO2e Production</td>
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</tr>
<tr>
<td>Total CO2e Production</td>
<td>0.000000 LB/HR</td>
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</table>

### INPUT DATA
**TWO PHASE FLASH**

**MAXIMUM NO. ITERATIONS** 30
**CONVERGENCE TOLERANCE** 0.000010000
**OUTLET PRESSURE: MINIMUM OF INLET STREAM PRESSURES**

**BLOCK:** P101  **MODEL:** PUMP

---

**INLET STREAM:** 2  
**OUTLET STREAM:** S116  
**PROPERTY OPTION SET:** UNIQAC UNIQAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>MASS (LB/HR)</td>
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<tr>
<td>ENTHALPY (BTU/HR)</td>
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<td>-0.236459E-04</td>
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*** 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 ***

- **OUTLET PRESSURE PSIA** 72.5189
- **DRIVER EFFICIENCY** 1.00000

**FLASH SPECIFICATIONS:**

- **LIQUID PHASE CALCULATION** NO
- **MAXIMUM NUMBER OF ITERATIONS** 30
- **TOLERANCE** 0.000010000

*** RESULTS ***

- **VOLUMETRIC FLOW RATE CUFT/HR** 5,990.91
- **PRESSURE CHANGE PSI** 37.7098
- **NPSH AVAILABLE FT-LBF/LB** 69.3238
- **FLUID POWER HP** 16.4303
- **BRAKE POWER HP** 21.9719
- **ELECTRICITY KW** 16.3844
- **PUMP EFFICIENCY USED** 0.74779
- **NET WORK REQUIRED HP** 21.9719
- **HEAD DEVELOPED FT-LBF/LB** 92.4959

---

**BLOCK:** P301  **MODEL:** PUMP

---

**INLET STREAM:** S303  
**OUTLET STREAM:** S304  
**PROPERTY OPTION SET:** UNIQAC UNIQAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th></th>
<th>IN</th>
<th>OUT</th>
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<tr>
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<td>MASS (LB/HR)</td>
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*** CO2 EQUIVALENT SUMMARY ***

- **FEED STREAMS CO2E** 3.30868 LB/HR
- **PRODUCT STREAMS CO2E** 3.30868 LB/HR
- **NET STREAMS CO2E PRODUCTION** 0.00000 LB/HR

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UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2E PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***
OUTLET PRESSURE PSIA 575.000
DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:
LIQUID PHASE CALCULATION
NO FLASH PERFORMED
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.0000100000

*** RESULTS ***
VOLUMETRIC FLOW RATE CUFT/HR 9,476.08
PRESSURE CHANGE PSI 350.000
NPSH AVAILABLE FT-LBF/LB 0.0
FLUID POWER HP 241.209
BRAKE POWER HP 308.204
ELECTRICITY KW 229.827
PUMP EFFICIENCY USED 0.78263
NET WORK REQUIRED HP 308.204
HEAD DEVELOPED FT-LBF/LB 1,691.03

BLOCK: R101 MODEL: RSTOIC

-----------
INLET STREAM: S15
OUTLET STREAM: S108
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

TOTAL BALANCE
MOLE(LBMOL/HR) 30996.5 33892.2 2895.75 0.00000
MASS (LB/HR) 807550 807550 -0.144159E-15
ENTHALPY(JT/HR) -0.216583E+10 -0.200387E+10 -0.747796E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 2.97761 LB/HR
PRODUCT STREAMS CO2E 5085.66 LB/HR
NET STREAMS CO2E PRODUCTION 5082.68 LB/HR
UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2E PRODUCTION 5082.68 LB/HR

*** INPUT DATA ***

STOICHIOMETRY MATRIX:

REACTION # 1:
SUBSTREAM MIXED : PROPANE -1.00 : PROPENE 1.00 HYDROGEN 1.00

REACTION # 2:
SUBSTREAM MIXED : PROPANE -1.00 : METHANE 1.00 ETHENE 1.00

REACTION # 3:
SUBSTREAM MIXED : HYDROGEN -1.00 : ETHANE 1.00 ETHENE -1.00

REACTION CONVERSION SPECS: NUMBER= 3
REACTION # 1:
SUBSTREAM:MIXED KEY COMP:PROPANE CONV FRAC: 0.3130

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~AP6A60.tmp

REACTION # 2:
SUBSTREAM:MIXED  KEY COMP:PROPANE  CONV FRAC: 0.2000E-02

REACTION # 3:
SUBSTREAM:MIXED  KEY COMP:ETHENE  CONV FRAC: 0.3000

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE F 1,094.00
SPECIFIED PRESSURE PSIA 73.0000
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000
SERIES REACTIONS GENERATED NO

*** RESULTS ***
OUTLET TEMPERATURE F 1094.0
OUTLET PRESSURE PSIA 73.000
HEAT DUTY BTU/HR 0.16196E+09
VAPOR FRACTION 1.0000

REACTION EXTENTS:

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V-L PHASE EQUILIBRIUM:

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BLOCK: R102  MODEL: RSTOIC

INLET STREAMS: S108 S109
OUTLET STREAM: 1
OUTLET HEAT STREAM: S2
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

******************************************************************************
* CONVERSION FRACTIONS OF ONE OR MORE COMPONENTS WERE MODIFIED *
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*** MASS AND ENERGY BALANCE ***

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169
TOTAL BALANCE

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<tr>
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*** CO2 EQUIVALENT SUMMARY ***

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<tr>
<td>PRODUCT STREAMS CO2E</td>
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<tr>
<td>NET STREAMS CO2E PRODUCTION</td>
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<tr>
<td>UTILITIES CO2E PRODUCTION</td>
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*** INPUT DATA ***

STOICHIOMETRY MATRIX:

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REACTION CONVERSION SPECS: NUMBER = 5
REACTION # 1:
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| SUBSTREAM MIXED | KEY COMP: PROPANE | CONV FRAC: 0.1100E-02 |
| SUBSTREAM MIXED | KEY COMP: PROPANE | CONV FRAC: 0.8000E-02 |
| SUBSTREAM MIXED | KEY COMP: PROPANE | CONV FRAC: 0.4000E-02 |
| SUBSTREAM MIXED | KEY COMP: ETHENE | CONV FRAC: 0.3000 |

REACTION EXTENT SPECS: NUMBER = 1
REACTION # 6: EXTENT = 983.9 LB/MOL/HR

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE F 1,094.00
SPECIFIED PRESSURE PSIA 56.3000
MAXIMUM NO. ITERATIONS 30

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CONVERGENCE TOLERANCE 0.000100000
SERIES REACTIONS
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES NO

*** RESULTS ***
OUTLET TEMPERATURE F 1094.0
OUTLET PRESSURE PSIA 56.300
HEAT DUTY BTU/HR -0.68346E+08
VAPOR FRACTION 1.0000

REACTION EXTENTS:

<table>
<thead>
<tr>
<th>REACTION NUMBER</th>
<th>REACTION EXTENT LBMOL/HR</th>
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<tbody>
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V-L PHASE EQUILIBRIUM:

<table>
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<th>Y(I)</th>
<th>K(I)</th>
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 BLOCK: SP101 MODEL: FSPLIT

INLET STREAM: S1
OUTLET STREAMS: S3 2
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

   IN       OUT
TOTAL BALANCE MOLE(LBMOL/HR) 21692.2 21692.2 0.00000
MASS(LB/HR ) 390791. 390791. 0.148948E-15
ENTHALPY(BTU/HR ) -0.262700E+10 -0.262700E+10 0.00000

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 LB/HR
PRODUCT STREAMS CO2E 0.00000 LB/HR
NET STREAMS CO2E PRODUCTION 0.00000 LB/HR
UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2 PRODUCTION 0.00000 LB/HR

*** INPUT DATA ***
FRACTION OF FLOW STRM=S3 FRAC= 0.100000

*** RESULTS ***

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171
STREAM = S3  SPLIT = 0.100000  KEY = 0  STREAM-ORDER = 1
2 0.900000 0

BLOCK: T101  MODEL: COMP

INLET STREAM:  S111
OUTLET STREAM:  S112
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

IN OUT RELATIVE DIFF.

TOTAL BALANCE
MOLE (LBMOI/HR)  35313.9  35313.9  0.00000
MASS (LB/HR)    824709.  824709.  0.00000
ENTHALPY (BTU/HR) -0.236542E+10 -0.238191E+10 0.776505E-02

*** CO2 EQUILVALENT SUMMARY ***

FEED STREAMS CO2E  12430.4  LB/HR
PRODUCT STREAMS CO2E  12430.4  LB/HR
NET STREAMS CO2E PRODUCTION  0.00000  LB/HR
UTILITIES CO2E PRODUCTION  0.00000  LB/HR
TOTAL CO2E PRODUCTION  0.00000  LB/HR

*** INPUT DATA ***

ISENTROPIC TURBINE
OUTLET PRESSURE PSIA  34.8091
ISENTROPIC EFFICIENCY  0.72000
MECHANICAL EFFICIENCY  1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP  -7,269.93
BRAKE HORSEPOWER REQUIREMENT HP  -7,269.93
NET WORK REQUIRED HP  -7,269.93
POWER LOSSES HP  0.0
ISENTROPIC HORSEPOWER REQUIREMENT HP  -10,097.1
CALCULATED OUTLET TEMP F  419.503
ISENTROPIC TEMPERATURE F  403.199
EFFICIENCY (POLYT/ISENT) USED  0.72000
OUTLET VAPOR FRACTION  1.00000
HEAD DEVELOPED FF-LB/LB  -24,241.6
MECHANICAL EFFICIENCY USED  1.00000
INLET HEAT CAPACITY RATIO  1.18360
INLET VOLUMETRIC FLOW RATE, CUFT/HR  6,644,400.
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR  9,571,030.
INLET COMPRESSIBILITY FACTOR  1.00000
OUTLET COMPRESSIBILITY FACTOR  1.00000
AV. ISENT. VOL. EXPONENT  1.18663
AV. ISENT. TEMP EXPONENT  1.18663
AV. ACTUAL VOL. EXPONENT  1.12578
AV. ACTUAL TEMP EXPONENT  1.12578
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**Total Flow:**
- LB/MOL/HR: 3.5660+04
- LB/HR: 8.3155+05
- VAPOR: 1.1961+07

**State Variables:**
- Temp: 1094.0000
- Pres: 173.8599
- Vfrac: 1.0000
- Lfrac: 0.0000

**Enthalpy:**
- BTU/LB/MOL: -5.7947+04
- BTU/LB: -2485.0316
- BTU/HR: -2.0664+09
- ENTHROPY: BTU/LB/MOL-R: -6.7185
- BTU/LB-R: -0.2881

**Density:**
- LB/MOL/CUFT: 3.3767-03
- LB/CUFT: 7.8740-02

**AVG:**
- 23.3186

**Mixed Substream Properties:**

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**SUBSTREAM: MIXED**

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**COMPONENTS: LB/HR**

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**TOTAL FLOW:**

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**STATE VARIABLES:**

| TEMP F    | 176.0000 | 77.0000 | 165.7922 | 77.0000 | 466.6963 |
| PRESS PSIA| 34.8091  | 72.5189 | 72.5189  | 72.5189 | 72.5189  |
| VFRAC     | 0.0      | 0.0     | 0.0      | 1.0000  | 1.0000   |
| LFRAC     | 1.0000   | 1.0000  | 1.0000   | 0.0     | 0.0      |
| SFRAC     | 0.0      | 0.0     | 0.0      | 0.0     | 0.0      |

**ENTHALPY:**

| BTU/LBMOL | -1.2110e+05| -1.2287e+05| -1.2126e+05| -4.5004e+04| -1.0076e+05|
| BTU/LB    | -6722.2463 | -6820.4298 | -6730.7001 | -1020.3862 | -5593.2896|
| BTU/HR    | -2.0270e+09| -2.3023e+08| -2.5945e+09| -2.1977e+08| -2.1561e+09|

**ENTROPY:**

| BTU/LB-R    | -1.9951  | -2.1629  | -2.0091  | -1.5305  | -0.5169 |

**DENSITY:**

| LBMOL/CUBF | 3.3673  | 3.4443  | 3.2747  | 1.2592e-02 | 7.2948e-03 |
| LBMOL/CUBF | 60.6632 | 62.0507 | 58.9950 | 0.5553    | 0.1314    |

**AVG MW**

| 18.0153 | 18.0153 | 18.0153 | 44.0965  | 18.0153  |

**MIXED SUBSTREAM PROPERTIES:**

*** ALL PHASES ***

| TEMP F    | 176.0000 | 77.0000 | 165.7822 | 77.0000 | 466.6963 |
| PRESS PSIA| 34.8091  | 72.5189 | 72.5189  | 72.5189 | 72.5189  |
| BTU/HR    | -2.0270e+09| -2.3023e+08| -2.5945e+09| -2.1977e+08| -2.1561e+09|
| S105 S108 S109 S110 S111 | **-----------------------------**

**STREAM ID**

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**STATE VARIABLES:**

| TEMP | 288.2717 | 1094.0000 | 1094.0000 | 1210.7455 | 460.8083 |
| PRES | 72.5189 | 73.0000 | 73.0000 | 52.5000 | 52.5000 |
| VFRAC | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| LFRAC | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| SFRAC | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**ENTROPY:**

| BTU/LBMOL | -8.2621+04 | -5.9125+04 | 7727.2183 | -5.5737+04 | -6.6926+04 |
| BTU/LB    | -3171.2595 | -2481.4258 | 241.4846 | -2386.6621 | -2865.7580 |
| BTU/HR    | -2.5609+09 | -2.0039+09 | 5.7954+06 | -1.9683+09 | -2.3634+09 |

**DENSITY:**

| LB/LMBOL | 9.0350-03 | 4.3783-03 | 4.3783-03 | 2.9243-03 | 5.3148-03 |
| LB/CUFT  | 0.2354 | 0.1043 | 0.1401 | 6.8294-02 | 0.1241 |
| AVG MW   | 26.0529 | 23.8270 | 31.9988 | 23.3537 | 23.3537 |

**MIXED SUBSTREAM PROPERTIES:**

| TEMP | 288.2717 | 1094.0000 | 1094.0000 | 1210.7455 | 460.8083 |
| PRES | 72.5189 | 73.0000 | 73.0000 | 52.5000 | 52.5000 |
| MFIX | BTU/HR | -2.5609+09 | -2.0039+09 | 5.7954+06 | -1.9683+09 | -2.3634+09 |
| COMPONENTS: LB MOL/HR |
|------------------------|----------------|----------------|----------------|----------------|
| PROPAINE               | 4844.6952      | 4844.6952      | 0.0            | 9223.3119      | 0.0            |
| PROPANE                | 4633.5591      | 4633.5591      | 0.0            | 356.5092       | 0.0            |
| HYDROGEN               | 3322.1622      | 3322.1622      | 0.0            | 5.9663-05      | 0.0            |
| OXYGEN                 | 0.0            | 0.0            | 0.0            | 0.0            | 0.0            |
| WATER                  | 2.2301-04      | 606.7342       | 1.9523-04      | 2.1416-04      | 578.2975       |
| CO                     | 58.3703        | 58.3703        | 0.0            | 5.0278-04      | 0.0            |
| CO2                    | 117.7321       | 117.7321       | 0.0            | 5.1573-02      | 0.0            |
| METHANE                | 18.0742        | 18.0742        | 0.0            | 1.7656-03      | 0.1807          |
| ETHANE                 | 8.2988         | 8.2988         | 0.0            | 0.1865         | 8.2988-02      |
| ETHENE                 | 10.0203        | 10.0203        | 0.0            | 6.3526-02      | 0.0            |

| COMPONENTS: LB/HR |
|------------------|----------------|----------------|----------------|----------------|
| PROPAINE          | 2.1363-05      | 2.1363-05      | 0.0            | 4.0672-05      | 0.0            |
| PROPANE           | 1.9498-05      | 1.9498-05      | 0.0            | 1.5002-04      | 0.0            |
| HYDROGEN          | 6697.0804      | 6697.0804      | 0.0            | 1.2027-04      | 0.0            |
| OXYGEN            | 0.0            | 0.0            | 0.0            | 0.0            | 0.0            |
| WATER             | 4.0176-05      | 1.0967-04      | 3.5171-05      | 3.8582-04      | 1.0418+04      |
| CO                | 1634.9760      | 1634.9760      | 0.0            | 1.4082-02      | 0.0            |
| CO2               | 5181.3675      | 5181.3675      | 0.0            | 2.2697         | 0.0            |
| METHANE           | 289.9195       | 289.9195       | 0.0            | 2.8324-02      | 2.8996         |
| ETHANE            | 249.5730       | 249.5730       | 0.0            | 5.6082         | 2.4957         |
| ETHENE            | 281.1069       | 281.1069       | 0.0            | 1.7821         | 0.0            |

| TOTAL FLOW: |
|--------------|----------------|----------------|----------------|----------------|
| LB MOL/HR    | 3.5314-04      | 1.3622-04      | 1.9523-04      | 3.0996+04      | 578.5612       |
| LB/HR        | 8.2471-05      | 4.3392-05      | 3.5171+05      | 8.0755+05      | 1.0424+04      |
| CUF'T/HR     | 9.5716+06      | 2.6691+06      | 5991.4609      | 7.1261+06      | 177.9018       |

| STATE VARIABLES: |
|-------------------|----------------|----------------|----------------|----------------|
| TEMP F            | 419.5034       | 176.0000       | 174.0116       | 1094.0000      | 176.0000       |
| PRES PSIA         | 34.8091        | 34.8091        | 72.5189        | 72.5189        | 34.8091        |
| VFRAC             | 0.0             | 0.0             | 1.0000         | 1.0000         | 0.0            |
| LFRAC             | 0.0             | 0.0             | 1.0000         | 1.0000         | 0.0            |
| SFRAC             | 0.0             | 0.0             | 0.0            | 0.0            | 0.0            |

| ENTHALPY: |
|-----------|----------------|----------------|----------------|----------------|
| BTU/LB MOL| -6.7450+04     | -1.7973-04     | -1.2110-05     | -6.9874+04     | -1.2102+05     |
| BTU/LB    | -2.8881.1876   | -564.1984      | -672.0873      | -2681.9833     | -671.3312      |
| BTU/HR    | -2.3819+09     | -2.4482+08     | -2.3642+09     | -2.1659+09     | -7.0019+07     |

| ENTROPY: |
|----------|----------------|----------------|----------------|----------------|
| BTU/LB -R     | -0.5973       | -0.9904        | -1.9956        | -0.5171        | -1.9918        |

| DENSITY: |
|----------|----------------|----------------|----------------|----------------|
| LB MOL/CUFT | 3.6894-03   | 5.1027-03      | 3.2585         | 4.3495-03      | 3.2521         |
| LB/CUFT    | 8.6162-02    | 0.1625         | 58.7022        | 0.1133         | 58.5918        |
| AVG Mn     | 23.3537       | 31.8550        | 38.1853        | 26.0529        | 18.0164        |

**MIXED SUBSTREAM PROPERTIES:**

| *** ALL PHASES *** |
|-------------------|----------------|----------------|----------------|----------------|
| TEMP F            | 419.5034       | 176.0000       | 174.0112       | 1094.0000      | 176.0000       |
| PRES PSIA         | 34.8091        | 34.8091        | 72.5189        | 72.5189        | 34.8091        |
| HFLUX BTU/HR     | -2.3819+09     | -2.4482+08     | -2.3642+09     | -2.1659+09     | -7.0019+07     |

| STREAM IDS        |
|-------------------|----------------|----------------|----------------|----------------|
| S203   | S204   | S205   | S206   | S207   |

| FROM   |
|--------|----------------|----------------|----------------|----------------|
| AD201  | MEA201         | MEA201         | C201           | C202           |

| TO     |
|--------|----------------|----------------|----------------|----------------|
| MEA201 | ----            | C201           | C202           | B202           |

| SUBSTREAM: MIXED |
|------------------|----------------|----------------|----------------|----------------|
| PHASE:           | VAPOR          | VAPOR          | VAPOR          | VAPOR          | VAPOR          |
COMPONENTS: LB/MOL/HR
PROPALE: 4844.6952 0.0 4844.6952 4844.6952 4844.6952
PROPENE: 4633.5591 0.0 4633.5591 4633.5591 4633.5591
HYDROGEN: 3322.1622 3.1222 3318.8401 3318.8401 3318.8401
OXYGEN: 0.0 0.0 0.0 0.0
WATER: 20.4367 0.0 21.6101 21.6101 21.6101
CO: 58.3703 0.0 58.3703 58.3703 58.3703
CO2: 117.7321 0.0 7.0639 7.0639 7.0639
METHANE: 17.8934 0.0 17.8934 17.8934 17.8934
ETHANE: 8.2168 0.0 8.2168 8.2168 8.2168
ETHENE: 10.0203 0.0 10.0203 10.0203 10.0203

COMPONENTS: LB/HR
PROPALE: 2.1363E+05 0.0 2.1363E+05 2.1363E+05 2.1363E+05
PROPENE: 1.9498E+05 0.0 1.9498E+05 1.9498E+05 1.9498E+05
HYDROGEN: 6697.0804 6.6971 6690.3833 6690.3833 6690.3833
OXYGEN: 0.0 0.0 0.0 0.0
WATER: 548.3259 0.0 389.3114 389.3114 389.3114
CO: 1634.9760 0.0 1634.9760 1634.9760 1634.9760
CO2: 5181.3675 4870.4854 310.8820 310.8820 310.8820
METHANE: 287.0599 0.0 287.0599 287.0599 287.0599
ETHANE: 247.0773 0.0 247.0773 247.0773 247.0773
ETHENE: 281.1069 0.0 281.1069 281.1069 281.1069

TOTAL FLOW:
LB/MOL/HR: 1.3043E+04 122.8170 1.2920E+04 1.2920E+04 1.2920E+04
LB/HR: 4.2349E+05 526.1970 4.1846E+05 4.1846E+05 4.1846E+05
CUFT/HR: 2.5561E+06 2.4069E+04 2.5320E+06 1.0453E+06 4.0814E+05

STATE VARIABLES:
TEMP: 176.0000 176.0000 176.0000 294.1946 423.4211
PRES: 34.8091 34.8091 34.8091 100.0000 100.0000
VFRAC: 1.0000 1.0000 1.0000 1.0000 1.0000
LFRAC: 0.0 0.0 0.0 0.0 0.0
SFRC: 0.0 0.0 0.0 0.0 0.0

ENTHALPY:
BTU/LB/ML: -1.4155E+04 -1.5903E+05 -1.2818E+04 -1.0843E+04 -8416.4966

ENTROPY:
BTU/LB/ML-R: -32.8089 0.4358 -33.2208 -32.4714 -31.6865

DENSITY:
LB/ML/CUFT: 5.1027E-03 5.1027E-03 5.1027E-03 1.2361E-02 3.1656E-02

MIXED SUBSTREAM PROPERTIES:

STREAM ID: S3 S3 S3 S3 S3
FROM: SP101 DC201 DC301 DC301 PD301
TO: DC301 B6 P301 HM301

SUBSTREAM: MIXED PHASE:
COMPONENTS: LB/MOL/HR
PROPALE: 0.0 4843.3406 2801.5579 2041.7527 2041.7527
PROPENE: 0.0 4582.7003 10.9528 4571.7475 4571.7475
HYDROGEN         0.0          6.6292e-05    0.0          6.6292e-05    6.6292e-05
OXYGEN           0.0          0.0            0.0          0.0            0.0
WATER            2169.2211  21.6101       21.6101       0.0            0.0
CO               0.0          5.5859e-04    0.0          5.5859e-04    5.5859e-04
CO2              0.0          5.7303e-02    0.0          5.7303e-02    5.7303e-02
METHANE          0.0          1.9617e-03    0.0          1.9617e-03    1.9617e-03
ETHANE           0.0          0.2072        8.4722e-28   0.2072        0.2072
ETHENE           0.0          7.0584e-02    0.0          7.0584e-02    7.0584e-02

COMPONENTS: LB/HR

PROPANE          0.0          2.1357e+05  1.2354e+05   9.0036e+04   9.0036e+04
PROPENE          0.0          1.9284e+05  4.6089e+05   1.9238e+05   1.9238e+05
HYDROGEN         0.0          1.3364e-04   0.0          1.3364e-04   1.3364e-04
OXYGEN           0.0          0.0           0.0          0.0           0.0
WATER            3.9079e+04  388.3114     389.3114     0.0           0.0
CO               0.0          1.5646e-02   0.0          1.5646e-02   1.5646e-02
CO2              0.0          2.5219        2.7305e-34   2.5219        2.5219
METHANE          0.0          3.1472e-02   0.0          3.1472e-02   3.1472e-02
ETHANE           0.0          6.2314        2.5476e-26   6.2314        6.2314
ETHENE           0.0          1.9802        1.4771e-35   1.9802        1.9802

TOTAL FLOW:

LB/HR            2169.2211  9447.9886    2834.1208    6613.8679    6613.8679
CFT/HR           665.6167   1.4441e+04  4.4165e+05   9.4760e+05   9.5383e+05

STATE VARIABLES:

TEMP           173.8599   124.8463    121.1944     102.9747     105.9465
PRES           34.8091    281.9800    244.6800     225.0000     575.0000
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/LB          -1.2130e+05 -2.3480e+04 -4.9982e+04 -1.3106e+04 -1.2988e+04
BTU/LB          -672.22463  -545.3000   -1138.8023   -306.9180   -304.1412
BTU/HR          -2.6270e+08 -2.2184e+08 -1.4165e+08 -8.6682e+07 -8.5898e+07

ENTROPY:

BTU/LB-MOL-R    -35.9555    -61.3611    -77.2836     -56.7877     -56.5991
BTU/LB-MOL-R    -1.9958     -1.4251     -1.7809      -1.3298      -1.3214

DENSITY:

LB/LB          3.2588       0.6543      0.6417       0.6890       0.6934
LB/CFT         58.7076      28.1711     28.1643      28.8043      29.6089
AVG MW         18.0153      45.0586     43.8899      42.7024      42.7024

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

TEMP           173.8599   124.8463    121.1944     102.9747     105.9465
PRES           34.8091    281.9800    244.6800     225.0000     575.0000
HFLMX           -2.6270e+08 -2.2184e+08 -1.4165e+08 -8.6682e+07 -8.5898e+07

S305 S306 S307 S308 S309
---------------------------------------------------------------------------------

STREAM ID     S305 S306 S307 S308 S309
FROM           HX301 H301 M301 C302 C303
TO              H301 M301 C302 C303 HX301

SUBSTREAM: MIXED/LB/HR

COMPONENTS: LB/HR

PROPENE         4571.7475  4571.7475   4186.5784    4186.5764    4186.5784
HYDROGEN        6.6292e-05 6.6292e-05   0.0          0.0          0.0
OXYGEN          0.0         0.0         0.0          0.0          0.0
WATER           0.0         0.0         0.0          0.0          0.0

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**MIXED SUBSTREAM PROPERTIES:**

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TOTAL FLOW:

| LBMOL/HR | 4207.6164 | 4207.6164 | 2834.1208 | 9840.5485 | 7000.0000 |
| LB/HR    | 1.7710+05 | 1.7710+05 | 1.2439+05 | 2.5860+05 | 2.2399+05 |
| CUF/HR   | 1.4203+05 | 5484.6963 | 4405.1185 | 1.1161+07 | 2.7067+06 |

STATE VARIABLES:

| TEMP (F) | 326.7204 | 100.0000 | 120.1047 | 1094.0000 | 70.0000 |
| PRES (PSIA) | 200.0000 | 200.0000 | 20.0000 | 14.7000 | 14.7000 |
| VFRAC     | 1.0000 | 0.0000 | 0.0000 | 1.0000 | 1.0000 |
| LRFRAC    | 0.0000 | 1.0000 | 0.0000 | 0.0000 | 0.0000 |
| SFRA      | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

ENTHALPY:

| BTU/LBML | 1.2934+04 | 1161.5962 | 5.0029+04 | 8.1899+04 | 49.0505 |
| BTU/LB    | 307.2803 | 75.1139 | -1139.8679 | -3116.4657 | -1.5329 |
| BTU/HR    | 5.4420+07 | 1.3303+07 | -1.4179+08 | -8.0593+08 | -3.4335+05 |

ENTROPY:

| BTU/LBML-R | -32.8596 | -46.9159 | -77.3556 | 5.2575 | -9.2547 |
| BTU/LB-R   | -0.7807 | -1.1622 | -1.7625 | 0.0001 | -2.8922 |

DENSITY:

| LBML/CUF | 2.9624-02 | 0.7193 | 0.6434 | 8.8166-04 | 2.5862-03 |
| CUF/MW    | 1.2469 | 30.2753 | 28.2374 | 2.3170-02 | 8.2754-02 |

AVG MW

| 42.0907 | 42.0907 | 43.8899 | 26.2794 | 31.9988 |

MIXED SUBSTREAM PROPERTIES:

| TEMP (F) | 326.7204 | 100.0000 | 120.1047 | 1094.0000 | 70.0000 |
| PRES (PSIA) | 200.0000 | 200.0000 | 20.0000 | 14.7000 | 14.7000 |
| HFLMX BTU/HR | 5.4420+07 | 1.3303+07 | -1.4179+08 | -8.0593+08 | -3.4335+05 |

S10 S11 S12 S13 S14

| CLASS: | HEAT | HEAT | HEAT | HEAT | HEAT |
| S10    | B3   | B3   | B3   | B3   | B3   |
| S11    | ---- | ---- | ---- | ---- | ---- |
| S12    | ---- | ---- | ---- | ---- | ---- |
| S13    | ---- | ---- | ---- | ---- | ---- |
| S14    | ---- | ---- | ---- | ---- | ---- |

STREAM ID

| Q (BTU/HR) | 5.3007+07 | 2.2034+08 | 5.4315+07 | 1.1345+07 | 1.6196+08 |
| TEG F      | 7.1795 | 7.1795 | 7.1795 | 7.1795 | 7.1795 |
| TEND F     | 1094.0000 | 1094.0000 | 1094.0000 | 1094.0000 | 1094.0000 |

S16 S2 S8 S9

| CLASS: | HEAT | HEAT | HEAT | HEAT |
| S16    | ---- | ---- | ---- | ---- |
| S16    | ---- | ---- | ---- | ---- |
| S2     | R102 | B2   | B3   | B3   |
| S8     | H101 | H000 | B3   | H101 |
| S9     | ---- | ---- | ---- | ---- |

STREAM ID

| CLASS: | HEAT | HEAT | HEAT | HEAT |
| S16    | ---- | ---- | ---- | ---- |
| S2     | ---- | ---- | ---- | ---- |
| S8     | ---- | ---- | ---- | ---- |
| S9     | ---- | ---- | ---- | ---- |
| STREAM ID | 1 |
| FROM : | R102 |
| TO : | H000 |

**SUBSTREAM: MIXED**

**PHASE:** VAPOR

**COMPONENTS: LB MOL/HR**

- PROPANE: 4844.7214
- PROPENE: 4658.3432
- HYDROGEN: 3322.1880
- OXYGEN: 0.0
- WATER: 2.2623+04
- CO: 58.3706
- CO2: 127.7333
- METHANE: 18.0743
- ETHANE: 8.3020
- ETHENE: 10.0206

**COMPONENTS: LB /HR**

- PROPANE: 2.1364+05
- PROPENE: 1.9603+05
- HYDROGEN: 6697.1324
- OXYGEN: 0.0
- WATER: 4.0755+05
- CO: 1634.9850
- CO2: 5181.4191
- METHANE: 289.9614
- ETHANE: 249.6368
- ETHENE: 281.1154

**TOTAL FLOW:**

- LB MOL/HR: 3.5660+04
- LB /HR: 8.3155+05
- CUFT/HR: 1.0561+07

**STATE VARIABLES:**

- TEMP F: 1094.0000
- PRES PSIA: 56.3000
- VFRAC: 1.0000
- LFRAC: 0.0
- SFRAC: 0.0

**ENTHALPY:**

- BTU/LB MOL: -5.7947+04
- BTU/LB: -2485.0316
- BTU/HR: -2.0664+09

**ENTROPY:**

- BTU/LB MOL: 6.7185
- BTU/LB: -0.2881

**DENSITY:**

- LB/CUFT: 3.3767+03
- LB/CUFT: 7.8740-02
- AVG MW: 23.3186

**MIXED SUBSTREAM PROPERTIES:**

*** ALL PHASES ***

- TEMP F: 1094.0000
- PRES PSIA: 56.3000
- HFLMX BTU/HR: -2.0664+09
STREAM ID 2
FROM : SP101
TO : P101

SUBSTREAM: MIXED
PHASE: LIQUID

COMPONENTS: LB/MOL/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 1.9523E+04
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

COMPONENTS: LB/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 3.5171E+05
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

TOTAL FLOW:
LB/MOL/HR 1.9523E+04
LB/HR 3.5171E+05
CFU/HR 9990.9099

STATE VARIABLES:
TEMP F 173.8599
PRES PSIA 34.8091
VFRC 0.0
LFRC 1.0000
SFRC 0.0

ENTRALPY:
BTU/LB/MOL -1.2110E+05
BTU/LB -6722.2463
BTU/HR -2.3643E+09

ENTROPY:
BTU/LB/MOL-R -35.9555
BTU/LB-R -1.9958

DENSITY:
LB/CFU 3.2588
LB/CFU 58.7076

MIXED SUBSTREAM PROPERTIES:
*** ALL PHASES ***
TEMP F 173.8599
PRES PSIA 34.8091
HFLUX BTU/HR -2.3643E+09
STREAM ID: 3  
FROM: DC201  
TO: B2  

SUBSTREAM: MIXED  
PHASE: VAPOR  
COMPONENTS: LB/MOL/HR  
PROPANE: 1.3546  
PROPENE: 50.8589  
HYDROGEN: 3318.8400  
OXYGEN: 0.0  
WATER: 0.0  
CO: 58.3698  
CO2: 7.0066  
METHANE: 17.8915  
ETHANE: 8.0096  
ETHENE: 9.9497  
COMPONENTS: LB/HR  
PROPANE: 59.7320  
PROPENE: 2140.1740  
HYDROGEN: 6690.3832  
OXYGEN: 0.0  
WATER: 0.0  
CO: 1634.9603  
CO2: 3083.6602  
METHANE: 287.0284  
ETHANE: 240.8459  
ETHENE: 279.1268  
TOTAL FLOW:  
LB/MOL/HR: 3472.2806  
LB/HR: 1.1641E+04  
CUFT/HR: 5.0171E+04  

STATE VARIABLES:  
TEMP F: -96.1354  
PRES PSIA: 270.0000  
VFRA: 1.0000  
LFRA: 0.0  
SFRA: 0.0  
ENTHALPY:  
BTU/LB/MOL: -2412.5808  
BTU/LB: -739.6493  
BTU/HR: -8.3772E+06  
ENTROPY:  
BTU/LB/MOL-R: -8.3778  
BTU/LB-R: -2.4990  
DENSITY:  
LB/MOL/CUFT: 6.9209-02  
LB/CUFT: 0.2320  
AVG MW: 3.3524  

MIXED SUBSTREAM PROPERTIES:  

---  

*** ALL PHASES ***  
TEMP F: -96.1354  
PRES PSIA: 270.0000  
HFLX BTU/HR: -8.3772E+06  

PURGE:  
STREAM ID: PURGE  
FROM: B1  

---

Page 12
TO : B2

SUBSTREAM: MIXED  PHASE: MIXED
COMPONENTS: LB/MOL/HR
             PROPANE  482.2303
             PROPENE  39.6122
             HYDROGEN 6.6292-06
             OXYGEN  0.0
             WATER  2.1610
             CO  5.5859-05
             CO2  5.7303-03
             METHANE 1.9617-04
             ETHANE  2.0723-02
             ETHENE  7.0584-03
COMPONENTS: LB/HR
             PROPANE  2.1265-04
             PROPENE 1666.9063
             HYDROGEN 1.8364-05
             OXYGEN  0.0
             WATER  38.9311
             CO  1.5646-03
             CO2  0.2122
             METHANE 3.1472-03
             ETHANE  0.6231
             ETHENE  0.1980
TOTAL FLOW:
           LB/MOL/HR  524.0372
           LB/HR  2.2972+04
           CFU/HR  1.1278+05
STATE VARIABLES:
           TEMP  F  -28.8264
           PRES  PSIA  20.0000
           VFRAC  0.9306
           LFRAC  6.9396-02
           SFRC  0.0
ENTHALPY:
           BTU/LB/MOL -4.3507+04
           BTU/LB  -992.5094
           BTU/HR  -2.2800+07
ENTROPY:
           BTU/LB/MOL-R -66.7457
           BTU/LB-R  -1.5226
DENSITY:
           LB/MOL/CFU  4.6465-03
           LB/CFU  0.2037
           AVG MW  43.8358

MIXED SUBSTREAM PROPERTIES:
*** ALL PHASES ***
           TEMP  F  -28.8264
           PRES  PSIA  20.0000
           HFLMX  BTU/HR  -2.2800+07
RECY

STREAM ID  RECY
FROM : B1
TO : H303
SUBSTREAM: MIXED
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**MIXED SUBSTREAM PROPERTIES:**

*** ALL PHASES ***

| TEMP | -28.8264 |
| PRES | 20.0000  |
| HFLMX| -2.0520+08 |

**S1**

STREAM ID: S1
FROM: M103
TO: SP101

**SUBSTREAM: MIXED**

PHASE: LIQUID

COMPONENTS: LBMOL/HR

PROPANE | 0.0
PROPENE  0.0
HYDROGEN  0.0
OXYGEN   0.0
WATER    2.1692E+04
CO       0.0
CO2      0.0
METHANE  0.0
ETHANE   0.0
ETHENE   0.0

COMPONENTS: LB/HR
PROPANE  0.0
PROPENE  0.0
HYDROGEN 0.0
OXYGEN   0.0
WATER    3.9079E+05
CO       0.0
CO2      0.0
METHANE  0.0
ETHANE   0.0
ETHENE   0.0

TOTAL FLOW:
LB/MOL/HR  2.1692E+04
LB/HR      3.9079E+05
CUFT/HR    6441.9834

STATE VARIABLES:
TEMP     F    176.0000
PRES PSIA 34.8091
VFRAC    0.0
LFRAC    1.0000
SFRAC    0.0

ENTHALPY:
BTU/LBMOL  -1.2110E+05
BTU/LB     -6722.2463
BTU/HR    -2.6270E+09

ENTROPY:
BTU/LBMOL-R  -35.9414
BTU/LB-R     -1.9951

DENSITY:
LB/MOL/CUFT 3.3673
LB/CUFT     60.6632
AVG MW      18.0153

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP     F    176.0000
PRES PSIA 34.8091
HFLMX     BTU/HR  -2.6270E+09

S2

STREAM ID     S2
FROM:          R102
TO:            H000
CLASS:         HEAT

STREAM ATTRIBUTES:
HEAT
Q  BTU/HR  6.8346E+07
TEG F     1094.0000
TEND F    1094.0000
S3
--

STREAM ID  S3
FROM :  SP101
TO :  ----

SUBSTREAM: MIXED
PHASE:  LIQUID

COMPONENTS: LB/MOL/HR
PROPANE  0.0
PROPENE  0.0
HYDROGEN  0.0
OXYGEN  0.0
WATER  2169.2211
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0

COMPONENTS: LB/HR
PROPANE  0.0
PROPENE  0.0
HYDROGEN  0.0
OXYGEN  0.0
WATER  3.9079+04
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0

TOTAL FLOW:
LB/MOL/HR  2169.2211
LB/HR  3.9079+04
CUFT/HR  665.6567

STATE VARIABLES:
TEMP  F  173.8599
PRES  PSIA  34.8091
VFrac  0.0
LFrac  1.0000
SFrac  0.0

ENTHALPY:
BTU/LB/MOL  -1.2110+05
BTU/LB  -6722.2463
BTU/HR  -2.6270+08

ENTROPY:
BTU/LB/MOL-R  -35.9555
BTU/LB-R  -1.9958

DENSITY:
LB/MOL/CUFT  3.2588
LB/CUFT  58.7076
AVG MW  18.0153

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP  F  173.8599
PRES  PSIA  34.8091
HFLNX  BTU/HR  -2.6270+08

S4
--

Page 16
STREAM ID: S4
FROM: B6
TO: MX301

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LB/MOL/HR
PROPANE 2801.5579
PROPENE 10.9528
HYDROGEN 0.0
OXYGEN 0.0
WATER 21.6101
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 8.4722-28
ETHENE 0.0

COMPONENTS: LB/HR
PROPANE 1.2354+05
PROPENE 460.8995
HYDROGEN 0.0
OXYGEN 0.0
WATER 389.3114
CO 0.0
CO2 2.7305-34
METHANE 0.0
ETHANE 2.5476-26
ETHENE 1.4771-35

TOTAL FLOW:
LB/MOL/HR 2834.1208
LB/HR 1.2439+05
CUFT/HR 4405.1185

STATE VARIABLES:
TEMP F 120.1047
PRES PSIA 20.0000
VFRAC 0.0
LFRAC 1.0000
SRAC 0.0

ENTHALPY:
BTU/LB/MOL -5.0029+04
BTU/LB -1139.8679
BTU/HR -1.4179+08

ENTROPY:
BTU/LB/MOL-R -77.3556
BTU/LB-R -1.7625

DENSITY:
LB/MOL/CUFT 0.6434
LB/CUFT 28.2374
AVG MW 43.8899

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 120.1047
PRES PSIA 20.0000
MFLX BTU/HR -1.4179+08

S6

STREAM ID: S6
FROM: B6
TO: ----
```
SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LB/MOL/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 2392.5913
WATER 5606.5414
CO 0.0
CO2 1841.4157
METHANE 0.0
ETHANE 0.0
ETHENE 0.0
COMPONENTS: LB/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 7.6560E+04
WATER 1.0100E+05
CO 0.0
CO2 8.1040E+04
METHANE 0.0
ETHANE 0.0
ETHENE 0.0
TOTAL FLOW:
LB/MOL/HR 9840.5485
LB/HR 2.5860E+05
Cuft/HR 1.1161E+07
STATE VARIABLES:
TEMP F 1094.0000
PRES PSIA 14.7000
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -8.1899E+04
BTU/LB -3116.4657
BTU/HR -8.0593E+08
ENTROPY:
BTU/LBMOL-R 5.2575
BTU/LB-R 0.2001
DENSITY:
LB/MOL/Cuft 8.8166E-04
LB/Cuft 2.3170E-02
AVG Mn 26.2794
MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

TEMP F 1094.0000
PRES PSIA 14.7000
HFLHX BTU/HR -8.0593E+08

S7

STREAM ID S7
FROM : ----
TO : B2

SUBSTREAM: MIXED
PHASE: VAPOR
```
COMPONENTS: LB MOL/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 7000.0000
WATER 0.0
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0
COMPONENTS: LB/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 2.2399E+05
WATER 0.0
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0
TOTAL FLOW:
LB MOL/HR 7000.0000
LB/HR 2.2999E+05
CUFT/HR 2.7067E+06
STATE VARIABLES:
TEMP °F 70.0000
PRES PSIA 14.7000
VFrac 1.0000
LFrac 0.0
SFrac 0.0
ENTHALPY:
BTU/LB MOL -49.0505
BTU/LB -1.5329
BTU/HR -3.4935E+05
ENTROPY:
BTU/LB MOL-R -9.2547E-02
BTU/LB-R -2.8922E-03
DENSITY:
LB MOL/CUFT 2.5862E-03
LB/CUFT 8.2754E-02
AVG MW 31.9988
MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP °F 70.0000
PRES PSIA 14.7000
HFLUX BTU/HR -3.4935E+05

S8

STREAM ID S8
FROM : 62
TO : B3
CLASS: HEAT

STREAM ATTRIBUTES:
HEAT
Q BTU/HR 7.7441E+08
TBEG °F 7.1795
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**STREAM ATTRIBUTES:**

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Page 20
### STREAM ATTRIBUTES: HEAT

**Q**  BTU/HR  1.1345e+07  
**TBEG**  F  7.1795  
**TEND**  F  1094.0000  

### STREAM ID  S14
**FROM :**  B3  
**TO :**  ----  
**CLASS:**  HEAT

### STREAM ATTRIBUTES: HEAT

**Q**  BTU/HR  1.6196e+08  
**TBEG**  F  7.1795  
**TEND**  F  1094.0000  

### STREAM ID  S15
**FROM :**  MX301  
**TO :**  R101  

#### PHASE: MIXED

**COMPONENTS:**  LB/MOL/HR

- **PROPANE:**  9223.3119
- **PROPENE:**  356.5092
- **HYDROGEN:**  9.9663-05
- **OXYGEN:**  0.0
- **WATER:**  2.1416e+04
- **CO:**  5.0273-04
- **CO2:**  5.1573-02
- **METHANE:**  1.7656-03
- **ETHANE:**  0.1865
- **ETHENE:**  6.3526-02

**COMPONENTS:**  LB/HR

- **PROPANE:**  4.0672e+05
- **PROPENE:**  1.5002e+04
- **HYDROGEN:**  1.2027e-04
- **OXYGEN:**  0.0
- **WATER:**  3.8582e+05
- **CO:**  1.4082e-02
- **CO2:**  2.2697
- **METHANE:**  2.8324e-02
- **ETHANE:**  5.6082
- **ETHENE:**  1.7821

#### TOTAL FLOW:

- **LB/MOL/HR:**  3.0996e+04
- **LB/HR:**  8.0755e+05
- **CUFT/HR:**  7.1265e+06

#### STATE VARIABLES:

- **TEMP:**  1094.0000
- **PRES:**  72.5189
- **VFRAC:**  1.0000
- **LFRAC:**  0.0
SFRAC: 0.0
ENTHALPY:
BTU/LBMOL: -6.9874E+04
BTU/LB: -2681.9833
BTU/HR: -2.1658E+09
ENTROPY:
BTU/LBMOL-R: -13.4731
BTU/LB-R: -0.5171
DENSITY:
LBMOL/CUFT: 4.3495E-03
LB/CUFT: 0.1133
AVG Mw: 26.0329

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
 TEMP  F  1094.0000
 PRES  PSIA  72.5189
 HFLMX  BTU/HR  -2.1658E+09

S16

---
STREAM ID: S16
FROM: ----
TO: M101
CLASS: HEAT

STREAM ATTRIBUTES:
HEAT Q: 1.6500E+08

S101

---
STREAM ID: S101
FROM: ----
TO: M101

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LBMOL/HR
PROPAINE: 0.0
PROPENE: 0.0
HYDROGEN: 0.0
OXYGEN: 0.0
WATER: 1873.9292
CO: 0.0
CO2: 0.0
METHANE: 0.0
ETHANE: 0.0
ETHENE: 0.0

COMPONENTS: LB/HR
PROPAINE: 0.0
PROPENE: 0.0
HYDROGEN: 0.0
OXYGEN: 0.0
WATER: 3.3759E+04
CO: 0.0
CO2: 0.0
METHANE: 0.0
ETHANE: 0.0
ETHENE: 0.0
TOTAL FLOW:
LB/HR 3.8547e+05
LB/HR 3.8547e+05

STATE VARIABLES:
TEMP F 77.0000
VFRAC 0.0
LFRAC 1.0000
SFRAc 0.0

ENTHALPY:
BTU/LBMOL -1.2287e+05
BTU/LB -6820.4298
BTU/HR -2.3025e+08

ENTROPY:
BTU/LBMOL-R -38.9652
BTU/LB-R -2.1629

DENSITY:
LB/CUFT 3.4443
LB/CUFT 62.0507
AVG Mw 18.0153

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 77.0000
VFRAC 0.0
LFRAC 1.0000
SFRAc 0.0

STREAM ID S102
FROM : MX101
TO : H101

SUBSTREAM: MIXED PHASE
COMPONENTS: LB/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 2.1397e+04
CO 0.0
CO2 0.0
ETHANE 0.0
ETHENE 0.0

COMPONENTS: LB/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 3.8547e+05
CO 0.0
CO2 0.0
ETHANE 0.0
ETHENE 0.0

TOTAL FLOW:
LB/HR 3.8547e+05
LB/HR 3.8547e+05
CUF/HR 6533.9742
STATE VARIABLES:
  TEMP  F   165.7822
  PRES  PSIA  72.5189
  VFRAC  0.0
  LFRAC  1.0000
  SFRAC  0.0
ENTHALPY:
  BTU/LBMOL  -1.2126e+05
  BTU/LB    -6730.7001
  BTU/HR   -2.5945e+09
ENTROPY:
  BTU/LBMOL-R  -36.1949
  BTU/LB-R     -2.0091
DENSITY:
  LBMOL/CUFT  3.2747
  LB/CUFT     58.9950
  AVG MW      38.0153

MIXED SUBSTREAM PROPERTIES:
*** ALL PHASES ***
  TEMP  F   165.7822
  PRES  PSIA  72.5189
  HFLHX  BTU/HR  -2.5945e+09
S103

STREAM ID  S103
FROM :    ----
TO :      MK102

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LBMOL/HR
PROPANE  4883.2391
PROPENE  0.0
HYDROGEN  0.0
OXYGEN  0.0
WATER  0.0
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0

COMPONENTS: LB/HR
PROPANE  2.1533e+05
PROPENE  0.0
HYDROGEN  0.0
OXYGEN  0.0
WATER  0.0
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0
TOTAL FLOW:
LBMOL/HR  4883.2391
LB/HR  2.1533e+05
CUF/HR  3.8761e+05
STATE VARIABLES:
  TEMP  F   77.0000
PRES  PSIA    72.5189
VFRAC  1.0000
LFRAC  0.0
SFRAc  0.0

ENTHALPY:
BTU/LB   MOL    -4.5004E+04
BTU/LB    -1020.5862
BTU/HR    -2.1977E+08

ENTROPY:
BTU/LB   MOL    -67.4897
BTU/LB    -1.5305

DEN SITY:
LB/MOL/CUFT    1.2592-02
LB/CUFT    0.5553

AVG MW    44.0965

MIXED  SUBSTREAM PROPERTIES:

***  ALL PHASES  ***

TEMP  F    77.0000
PRES  PSIA    72.5189
HFLX  BTU/HR    -2.1977E+08

S104  

STREAM ID    S104
FROM    M101
TO    M2102

SUBSTREAM: MIXED PHASE:  VAPOR

COMPONENTS: LB MOL/HR
PROPANE  0.0
PROPENE  0.0
HYDROGEN  0.0
OXYGEN  0.0
WATER    2.1397E+04
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0

COMPONENTS: LB/HR
PROPANE  0.0
PROPENE  0.0
HYDROGEN  0.0
OXYGEN  0.0
WATER    3.8547E+05
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0

TOTAL FLOW:
LB MOL/HR  2.1397E+04
LB/HR  3.8547E+05
CUFT/HR  2.9332E+06

STATE VARIABLES:
TEMP  F  466.6963
PRES  PSIA  72.5189
VFRAC  1.0000
LFRAC  0.0
SFRAC  0.0
ENTHALPY:
BTU/LB    -1.0076E+05
BTU/LB    -5593.2896
BTU/HR    -2.1561E+09
ENTROPY:
BTU/LB    -9.3117
BTU/LB    -0.5169
DENSITY:
LB/CUFT   7.2948-03
LB/CUFT   0.1314
AVG Mw    18.0153

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP   F    466.6963
PRES   PSIA  72.5189
HEATX  BTU/HR -2.1561E+09

S105
----

STREAM ID  S105
FROM        MK302
TO          HK401

MAX CONV. ERROR: 1.3573E-06
SUBSTREAM: MIXED

PHASE:
VAPOR

COMPONENTS: LB/MOL/HR
PROPANE    9223.3119
PROPENE    356.5092
HYDROGEN   5.9663E-05
OXYGEN     0.0
WATER      2.1416E+04
CO          5.0273E-04
CO2         5.1573E-02
METHANE    1.7656E-03
ETHANE     0.1865
ETHENE     6.3526E-02

COMPONENTS: LB/HR
PROPANE    4.0672E+05
PROPENE    1.5002E+04
HYDROGEN   1.2027E+04
OXYGEN     0.0
WATER      3.8582E+05
CO          1.4082E-02
CO2         2.2697
METHANE    2.8324E-02
ETHANE     5.6082
ETHENE     1.7621

TOTAL FLOW:
LB/MOL/HR   3.0996E+04
LB/HR       8.0755E+05
CUB/F    3.4907E+06

STATE VARIABLES:
TEMP   288.2717
PRES   PSIA  72.5189
VFRA   1.0000
LFRA   0.0
SFRAC  0.0
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#### Substream: Mixed

**Phase:** Vapor

**Components:** LB MOL/HR

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**Components:** LB/HR

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**Total Flow:**

| LB MOL/HR | 3.3892x04 |
| LB/HR     | 8.0755x05 |
| CUFT/HR   | 7.7409x06 |

**State Variables:**

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**Enthalpy:**

| BTU/LB MOL | -5.9125x04 |
| BTU/LB     | -2481.4258 |
BTU/HR -2.0039E+09

ENTROPY:
BTU/LB MOL -R -8.9101
BTU/LB -R -0.3740

DENSITY:
LB MOL/CUFT 4.3783-03
LB/CUFT 0.1043

AVG MW 22.8270

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 1094.0000
PRES PSIA 73.0000
HFLMX BTU/HR -2.0039E+09

S109

---

STREAM ID S109
FROM:
TO:

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LB MOL/HR
PROPA N 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 750.0000
WATER 0.0
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

COMPONENTS: LB/HR
PROPA N 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 2.3999+04
WATER 0.0
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

TOTAL FLOW:
LB MOL/HR 750.0000
LB/HR 2.3999+04
CUFT/HR 1.7130+05

STATE VARIABLES:
TEMP F 1094.0000
PRES PSIA 73.0000
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:
BTU/LB MOL 7727.2183
BTU/LB 241.4846
BTU/HR 5.7954+06

ENTROPY:
BTU/LB MOL -R 4.7795

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<tr>
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<td><strong>TOTAL FLOW:</strong></td>
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<tr>
<td>LBMOL/HR</td>
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<tr>
<td>LB/HR</td>
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<tr>
<td>CFUT/HR</td>
<td>1.2076+07</td>
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<td><strong>STATE VARIABLES:</strong></td>
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<td>BTU/HR</td>
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<tr>
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Page 29
**DENSITY:**
- LB/ML/CUFT: 2.9243-03
- LB/CUFT: 6.8294-02
- AVG MW: 23.3537

**MIXED SUBSTREAM PROPERTIES:**

<table>
<thead>
<tr>
<th>*** ALL PHASES ***</th>
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<tr>
<td>PRES PSIA</td>
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<td>HFLX BTU/HR</td>
<td>-1.9688+09</td>
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**S111**

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<td>TO</td>
<td>T101</td>
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**SUBSTREAM: MIXED**

**PHASE:** VAPOR

**COMPONENTS: LB/ML/CUFT**
- PROPANE: 4844.6952
- PROPENE: 4633.5391
- HYDROGEN: 3322.1622
- OXYGEN: 0.0
- WATER: 2.2301+04
- CO: 58.3703
- CO2: 1.17.7321
- METHANE: 18.0742
- ETHANE: 8.2998
- ETHENE: 10.0203

**COMPONENTS: LB/HR**
- PROPANE: 2.1363+05
- PROPENE: 1.9498+05
- HYDROGEN: 6697.0894
- OXYGEN: 0.0
- WATER: 4.0176+05
- CO: 1634.9760
- CO2: 5181.3675
- METHANE: 289.9595
- ETHANE: 249.5730
- ETHENE: 261.1069

**TOTAL FLOW:**
- LB/ML/CUFT: 3.5314+04
- LB/HR: 6.2471+05
- CUFT/HR: 6.6444+06

**STATE VARIABLES:**
- TEMP F: 460.8083
- PRES PSIA: 52.5000
- VFRAC: 1.0000
- LFRA: 0.0
- SFRAC: 0.0

**ENTHALPY:**
- BTU/LB/ML: -6.6926+04
- BTU/LB: -2865.7580
- BTU/HR: -2.3634+09

**ENTROPY:**
- BTU/LB/ML-R: -14.1825
- BTU/LB-R: -0.6073

**DENSITY:**
- LB/ML/CUFT: 5.3148-03
- LB/CUFT: 0.1241
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*** ALL PHASES ***

** Temp F 419.5034
** Pres PSIA 34.8091
** HFLNK BTU/HR -2.3819e+09

---

STREAM ID S114
FROM : H103
TO : A0201

SUBSTREAM: MIXED
PHASE: VAPOR

COMPONENTS: LB/MOL/HR
- PROPANE 4844.6952
- PROPENE 4632.5591
- HYDROGEN 3322.1622
- OXYGEN 0.0
- WATER 608.7342
- CO 58.3703
- CO2 117.7321
- METHANE 18.0742
- ETHANE 8.2998
- ETHENE 10.0203

COMPONENTS: LB/HR
- PROPANE 2.1363e+05
- PROPENE 1.9498e+05
- HYDROGEN 6697.0804
- OXYGEN 0.0
- WATER 1.0967e+04
- CO 1634.9760
- CO2 5181.3675
- METHANE 289.9595
- ETHANE 249.5730
- ETHENE 281.1069

TOTAL FLOW:
- LB/MOL/HR 1.3622e+04
- LB/HR 4.3392e+05
- CUFT/HR 2.6695e+06

STATE VARIABLES:
- Temp F 176.0000
- Pres PSIA 34.8091
- VFRAC 1.0000
- LFRAC 0.0
- SFRAC 0.0

ENTHALPY:
- BTU/LBMOL -1.7973e+04
- BTU/LB -564.1984
- BTU/HR -2.4482e+08

ENTROPY:
- BTU/LBMOL-R -31.5497
- BTU/LB-R -0.9904

DENSITY:
- LB/MOL/CUFT 5.1027-03
- LB/CUFT 0.1625
- AVG MW 31.8350

*** ALL PHASES ***

** Temp F 176.0000
Page 32
STREAM ID: S116
FROM: P101
TO: Mx101

SUBSTREAM: MIXED
PHASE: LIQUID

COMPONENTS: LB/MOL/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 1.9523e+04
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

COMPONENTS: LB/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 3.5171e+05
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

TOTAL FLOW:
LB/MOL/HR 1.9523e+04
LB/HR 3.5171e+05
CUFT/HR 5991.4609

STATE VARIABLES:
TEMP F 174.0112
PRES PSIA 72.5189
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
BTU/LB/MOL -1.2110e+05
BTU/LB -6722.0873
BTU/HR -2.3642e+09

ENTROPY:
BTU/LB/MOL-R -35.9511
BTU/LB-R -1.9956

DENSITY:
LB/MOL/CUFT 3.2585
LB/CUFT 58.7022
AVG MW 18.0153

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 174.0112
PRES PSIA 72.5189
HFLMX BTU/HR -2.3642e+09
STREAM ID: S202
FROM: AD201
TO: -----

SUBSTREAM: MIXED
PHASE: LIQUID

COMPONENTS: LB/HR MOL
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 578.2975
CO 0.0
CO2 0.0
METHANE 0.1807
ETHANE 8.2998-02
ETHENE 0.0

COMPONENTS: LB/HR MOL
PROPANE 0.0
PROPENE 0.0
HYDROGEN 0.0
OXYGEN 0.0
WATER 1.0418-04
CO 0.0
CO2 0.0
METHANE 2.8996
ETHANE 2.4957
ETHENE 0.0

TOTAL FLOW: LB/HR MOL 578.5612

STATE VARIABLES:
TEMP F 176.0000
PRESS PSIA 34.8091
VFRC 0.0
LFRC 1.0000
SFRC 0.0

ENTHALPY:
BTU/LB MOL -1.2102+05
BTU/LB -67.173352
BTU/HR -7.0019+07

ENTROPY:
BTU/LB MOL-R -35.8847
BTU/LB -R -1.9918

DENSITY:
LB/CFM 3.2521
LB/CF -U 58.5918

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 176.0000
PRESS PSIA 34.8091
HFLX BTU/HR -7.0019+07

S203
-----

~APF311.tmp
STREAM ID S203
FROM AD201
TO MEA201

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LB/MOL/HR
PROPANE 4844.6952
PROPIENE 4633.5591
HYDROGEN 3322.1622
OXYGEN 0.0
WATER 30.4367
CO 58.3703
CO2 127.7321
METHANE 17.8934
ETHANE 8.2168
ETHENE 10.0203

COMPONENTS: LB/HR
PROPANE 2.1363+05
PROPPIENE 1.9498+05
HYDROGEN 6697.0804
OXYGEN 0.0
WATER 548.3259
CO 1634.9760
CO2 5181.3675
METHANE 287.0599
ETHANE 247.0773
ETHENE 281.1069

TOTAL FLOW:
LB/MOL/HR 1.3043+04
LB/HR 4.2349+05
CUFT/HR 2.5561+06

STATE VARIABLES:
TEMP F 176.0000
PRES PSIA 34.8091
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:
BTU/LB/MOL -1.4195+04
BTU/LB -437.1884
BTU/HR -1.8515+08

ENTROPY:
BTU/LB/MOL-R -32.8089
BTU/LB-R -1.0105

DENSITY:
LB/MOL/CUFT 5.1027+03
LB/CUFT 0.1657
AVG MW 32.4689

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 176.0000
PRES PSIA 34.8091
MFLUX BTU/HR -1.8515+08

S204

STREAM ID S204
FROM MEA201
TO ----
SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LB/MOL/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 3.3222
OXYGEN 0.0
WATER 8.8266
CO 0.0
CO2 110.6682
METHANE 0.0
ETHANE 0.0
ETHENE 0.0
COMPONENTS: LB/HR
PROPANE 0.0
PROPENE 0.0
HYDROGEN 6.6971
OXYGEN 0.0
WATER 159.0145
CO 0.0
CO2 4870.4854
METHANE 0.0
ETHANE 0.0
ETHENE 0.0
TOTAL FLOW:
LB/MOL/HR 122.8170
LB/HR 5036.1970
CUFT/HR 2.4069E+04
STATE VARIABLES:
TEMP F 176.0000
PRES PSIA 34.8091
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0
ENTHALPY:
BTU/LB/MOL -1.5902E+05
BTU/LB -3877.9452
BTU/HR -1.9530E+07
ENTROPY:
BTU/LB/MOL-R 0.4358
BTU/LB-R 1.0628E-02
DENSITY:
LB/MOL/CUFT 5.1027-03
LB/CUFT 0.2092
AVG Mn 41.0057

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 176.0000
PRES PSIA 34.8091
HFLHX BTU/HR -1.9530E+07

S205

STREAM ID S205
FROM : MEA201
TO : C201

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LB/MOL/HR
PROPANE 4844.6952
PROPENE 4633.5591
HYDROGEN 3318.8401
OXYGEN 0.0
WATER 21.6101
CO 58.3703
CO2 7.0639
METHANE 17.8934
ETHANE 8.2168
ETHENE 10.0203

COMPONENTS: LB/HR
PROPANE 2.1363e+05
PROPENE 1.9498e+05
HYDROGEN 6690.3833
OXYGEN 0.0
WATER 389.3114
CO 1634.9760
CO2 320.8820
METHANE 287.0599
ETHANE 247.0773
ETHENE 281.1069

TOTAL FLOW:
LB/MOL/HR 1.2920e+04
LB/HR 4.1846e+05
CUFT/HR 2.5320e+06

STATE VARIABLES:
TEMP F 176.0000
PRES PSIA 34.8091
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:
BTU/LB/MOL -1.2818e+04
BTU/LB -395.7785
BTU/HR -1.6562e+08

ENTROPY:
BTU/LB/MOL-R -33.2208
BTU/LB-R -1.0257

DENSITY:
LB/CUFT 5.1027-03
LB/CUFT 0.1653

AVG MW 32.3877

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 176.0000
PRES PSIA 34.8091
HFLIX BTU/HR -1.6562e+08

S206

STREAM ID S206
FROM : C201
TO : C202

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LB/MOL/HR
PROPANE 4844.6952
PROPENE 4633.5591
HYDROGEN 33.188401
OXYGEN 0.0
WATER 21.6101
CO 58.3703
CO2 7.0639
METHANE 17.8934
ETHANE 8.2168
ETHENE 10.0203

COMPONENTS: LB/HR
PROPANE 2.1363E+05
PROPENE 1.9498E+05
HYDROGEN 66.903833
OXYGEN 0.0
WATER 389.3114
CO 1634.9760
CO2 310.8820
METHANE 287.0399
ETHANE 247.0773
ETHENE 281.1069

TOTAL FLOW:
LB/MOL/HR 1.2920E+04
LB/HR 4.1846E+05
CUFT/HR 1.0453E+06

STATE VARIABLES:
TEMP F 294.1946
PRES PSIA 100.0000
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:
BTU/LB/ML 1.0843E+04
BTU/LB 334.7887
BTU/HR 1.4010E+08

ENTROPY:
BTU/LB/ML-R 32.4714
BTU/LB-R 1.0002
DENSI:
LB/ML/CUFT 1.2361E-02
LB/CUFT 0.4003
AVG MW 32.3877

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 294.1946
PRES PSIA 100.0000
HFLMX BTU/HR 1.4010E+08

S207

STREAM ID: S207
FROM: C202
TO: DC201

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LB/ML/HR
PROPANE 4844.6952
PROPENE 4633.5591
HYDROGEN 33.188401
OXYGEN 0.0
WATER 21.6101

Page 38
COMPONENTS: LB/HR

PROPANE
PROPANE
HYDROGEN
OXYGEN
WATER
CO
CO2
METHANE
ETHANE
ETHENE

TOTAL FLOW:

LB/HR

CUFT/HR

STATE VARIABLES:

ENTHALPY:

ENTROPY:

DENSITY:

MIXED SUBSTREAM PROPERTIES:

STREAM ID
FROM :
TO :

SUBSTREAM: MIXED

PHASE:

COMPONENTS: LB/HR

PROPANE
PROPANE
HYDROGEN
OXYGEN
WATER
CO
CO2
METHANE

Page 39
<table>
<thead>
<tr>
<th>Component</th>
<th>Flow Rate (lb/hr)</th>
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<td>Oxygen</td>
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<td>Water</td>
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<td>CO</td>
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<td>Ethene</td>
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**Total Flow:**
- lb-mol/hr: 9447.9886
- lb/hr: 4.0682+05
- cuft/hr: 1.4441+04

**State Variables:**
- Temp (F): 124.8463
- Press (psia): 281.9800
- Vfrac: 0.0
- Lfrac: 1.0000
- Sfrac: 0.0

**Enthalpy:**
- BTU/lbmol: -2.3480+04
- BTU/lb: -545.3003
- BTU/hr: -2.2184+08

**Entropy:**
- BTU/lbmol-R: -61.3611
- BTU/lb-R: -1.4251

**Density:**
- lb/mo/l-cuft: 0.6143
- lb/cuft: 28.1711
- Avg MW: 43.0586

**Mixed Substream Properties:**

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<th>Component</th>
<th>Flow Rate (lb/hr)</th>
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**Substream:**
- ID: S302
- From: DC301
- To: B6

**Substream Properties:**

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<th>Flow Rate (lb/hr)</th>
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<td>Oxygen</td>
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<tr>
<td>CO2</td>
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<tr>
<td>Methane</td>
<td>0.0</td>
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<tr>
<td>Ethane</td>
<td>8.4722-28</td>
</tr>
<tr>
<td>Ethene</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Page 40
PROPANE       1.235405
PROPENE       460.8995
HYDROGEN      0.0
OXYGEN        0.0
WATER         389.3114
CO            0.0
CO2           2.7305-34
METHANE       0.0
ETHANE        2.5476-26
ETHENE        1.4771-35
TOTAL FLOW:
LB/HR         2834.1208
CUFT/HR       1.2439+05
STATE VARIABLES:
TEMP          121.1944
PRES          244.6800
VFRAC         0.0
LFRAc         1.0000
SFRAc         0.0
ENTHALPY:
BTU/LBMOL     -4.9982+04
BTU/LB        -1138.8023
BTU/HR        -1.4165+08
ENTROPY:
BTU/LBMOL-R   -77.2836
BTU/LB-R      -1.7609
DENSITY:
LB/MOL/CUFT   0.6417
LB/CUFT       28.1643
AVG Mw         43.8899
MIXED SUBSTREAM PROPERTIES:
**** ALL PHASES ****
TEMP          121.1944
PRES          244.6800
HFLMX         BTU/HR   -1.4165+08
S303
---
STREAM ID     S303
FROM          DC301
TO            P301
SUBSTREAM: MIXED PHASE:
COMPONENTS: LB MOL/HR
PROPANE       2041.7827
PROPENE       4571.7475
HYDROGEN      6.6292-05
OXYGEN        0.0
WATER         0.0
CO            5.5859-04
CO2           5.7303-02
METHANE       1.9617-03
ETHANE        0.2072
ETHENE        7.0584-02
COMPONENTS: LB/HR
PROPANE       9.0036+04
PROPENE       1.9238+05
HYDROGEN      1.3564-04
OXYGEN 0.0
WATER 0.0
CO 1.5646e-02
CO2 2.5219
METHANE 3.1472e-02
ETHANE 6.2314
ETHENE 1.9802
TOTAL FLOW:
LBMOL/HR 6613.8679
LB/HR 2.8243e+05
CUFT/HR 9476.0785
STATE VARIABLES:
TEMP F 102.9747
PRES PSIA 225.0000
VFrac 0.0
LFrac 1.0000
SFrac 0.0
ENTHALPY:
BTU/LBMOL -1.3106e+04
BTU/LB -306.9180
BTU/HR -8.6682e+07
ENTROPY:
BTU/LBMOL-R -56.7877
BTU/LB-R -1.3298
DENSITY:
LBMOL/ CUFT 0.6980
LB/CUFT 29.8043
AVG Mw 42.7024

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 102.9747
PRES PSIA 225.0000
HFLX BTU/HR -8.6682e+07

STREAM ID S304
FROM : P301
TO : HX301

SUBSTREAM: MIXED PHASE:
COMPONENTS:

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<tr>
<th>COMPONENT</th>
<th>LBMOL/HR</th>
<th>LB/HR</th>
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<tbody>
<tr>
<td>PROPANE</td>
<td>2041.7827</td>
<td>9.0036e+04</td>
</tr>
<tr>
<td>PROPENE</td>
<td>4571.7475</td>
<td>1.9238e+05</td>
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<tr>
<td>HYDROGEN</td>
<td>6.6252e-05</td>
<td>1.3364e-04</td>
</tr>
<tr>
<td>OXYGEN</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>WATER</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>CO</td>
<td>5.5859e-04</td>
<td>1.5646e-02</td>
</tr>
<tr>
<td>CO2</td>
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<td>0.9280e+05</td>
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<tr>
<td>METHANE</td>
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<td>1.3364e-04</td>
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<td>0.2072</td>
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<tr>
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<td>LB/HR</td>
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</table>
CO2 2.5219
METHANE 3.1472-02
ETHANE 6.2314
ETHENE 1.9802
TOTAL FLOW:
LB/MOL/HR 6613.8679
LB/HR 2.8243-05
CUFT/HR 9538.6338
STATE VARIABLES:
TEMP F 105.9465
PRES PSIA 575.0000
VFrac 0.0
LFRAC 1.0000
SFRAC 0.0
ENTHALPY:
BTU/LBMOL -1.2988+04
BTU/LB -304.1413
BTU/HR -8.5898+07
ENTROPY:
BTU/LBMOL-R -56.5991
BTU/LB-R -1.3254
DENSITY:
LB/MOL/CUART 0.6934
LB/CUART 29.6089
AVG MW 42.7024
MIXED SUBSTREAM PROPERTIES:
*** ALL PHASES ***
TEMP F 105.9465
PRES PSIA 575.0000
HFLUX BTU/HR -8.5898+07
S305
----
STREAM ID S305
FROM : HK301
TO : H301
SUBSTREAM: MIXED PHASE:
COMPONENTS: LB/MOL/HR
PROPANE 2041.7827
 PROPENE 4571.7475
HYDROGEN 6.6292-05
OXYGEN 0.0
WATER 0.0
CO 5.5859-04
CO2 5.7303-02
METHANE 1.9617-03
ETHANE 0.2072
ETHENE 7.0584-02
COMPONENTS: LB/HR
PROPANE 9.0036+04
PROPENE 1.9238+05
HYDROGEN 1.3364-04
OXYGEN 0.0
WATER 0.0
CO 1.5646-02
CO2 2.5219
METHANE 3.1472-02
ETHANE 6.2314
ETHENE  1.9802
TOTAL FLOW:
LB/HR  6613.8679
CUB/HR  9619.8001
STATE VARIABLES:
TEMP  F  109.6769
PRES  PSI  575.0000
VFRAC  0.0
LFRA  1.0000
SFRA  0.0
ENTHALPY:
BTU/LBMO  -1.2836+04
BTU/LB  -300.6006
BTU/HR  -8.4898+07
ENTROPY:
BTU/LBMO++R  -56.3604
BTU/LB++R  -1.3198
DENSITY:
LBMO/CF  0.6875
LB/CF  29.3591
AVG MW  42.7024
MIXED SUBSTREAM PROPERTIES:
*** ALL PHASES ***
TEMP  F  109.6769
PRES  PSI  575.0000
HFLXLK BTU/HR  -8.4898+07
S306
----
STREAM ID  S306
FROM  H301
TO  M301
SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS:
LB/HR
PROPANE  2041.7827
PROPENE  4571.7475
HYDROGEN  6.6292-05
OXYGEN  0.0
WATER  0.0
CO  5.5859-04
CO2  5.7303-02
METHANE  1.9617-03
ETHANE  0.2072
ETHENE  7.0564-02
COMPONENTS:
LB/HR
PROPANE  9.0036+04
PROPENE  1.9238+05
HYDROGEN  1.3364-04
OXYGEN  0.0
WATER  0.0
CO  1.5646-02
CO2  2.5219
METHANE  3.1472-02
ETHANE  6.2314
ETHENE  1.9802
TOTAL FLOW:
LB/HR  6613.8679
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<td>CUFT/HR</td>
<td>8.8463E+04</td>
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**STATE VARIABLES:**

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**ENTHALPY:**

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**ENTROPY:**

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**DENSITY:**

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**AVG MW:**

| 42.7024 |

**MIXED SUBSTREAM PROPERTIES:**

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<tr>
<td>HFLMX</td>
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**STREAM ID:**

| S307 |

**FROM:**

| M301 |

**TO:**

| C302 |

**SUBSTREAM: MIXED PHASE:**

**COMPONENTS:**

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<tbody>
<tr>
<td>PROPANE</td>
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<td>METHANE</td>
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<td>ETHENE</td>
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**COMPONENTS:**

<table>
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<th>LB/HR</th>
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<tbody>
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<td>METHANE</td>
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<tr>
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<td>ETHENE</td>
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**TOTAL FLOW:**

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<td>1.7710E+05</td>
</tr>
<tr>
<td>CUFT/HR</td>
<td>5.6279E+04</td>
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**STATE VARIABLES:**
TEMP  F  257.0000
PRES  PSIA  575.0000
VFRAC  1.0000
LFRAC  0.0
SFRAC  0.0

ENTHALPY:
BTU/LBMOL  1.1552E+04
BTU/LB  274.4508
BTU/HR  4.8606E+07

ENTROPY:
BTU/LBMOL-R  -36.3127
BTU/LB-R  -0.8637

DENSITY:
LBMOL/CUFT  7.4764E-02
LB/CUFT  3.1469

AVG MW  42.0907

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP  F  257.0000
PRES  PSIA  575.0000
HFLMX  BTU/HR  4.8606E+07

S308

---

STREAM ID  S308
FROM :  C302
TO :  C303

SUBSTREAM: MIXED PHASE: VAPOR

COMPONENTS: LBMOL/HR
PROPANE  21.0380
PROPENE  4.1865784
HYDROGEN  0.0
OXYGEN  0.0
WATER  0.0
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0

COMPONENTS: LB/HR
PROPANE  927.7032
PROPENE  1.7617E+05
HYDROGEN  0.0
OXYGEN  0.0
WATER  0.0
CO  0.0
CO2  0.0
METHANE  0.0
ETHANE  0.0
ETHENE  0.0

TOTAL FLOW:
LBMOL/HR  4207.6164
LB/HR  1.7710E+05
CUFT/HR  1.2493E+06

STATE VARIABLES:
TEMP  F  93.6757
PRES  PSIA  20.0000
VFRAC  1.0000

Page 46
LFRAC  0.0  
SFRAC  0.0  
ENTHALPY:    
BTU/LB MOL  8689.9830  
BTU/LB  206.4584  
BTU/HR  3.6564+07  
ENTROPY:    
BTU/LB MOL-R  -34.1963  
BTU/LB-R  -0.8124  
DENSITY:    
LB MOL/CUFT  3.3680+03  
LB/CUFT  0.1418  
AVG MW  42.0907  

MIXED SUBSTREAM PROPERTIES:  

*** ALL PHASES ***  
TEMP  F  93.6757  
PRES PSIA  20.0000  
HFL MIX BTU/HR  3.6564+07  

S309  
----  
STREAM ID  S309  
FROM  C303  
TO  HX301  

SUBSTREAM: MIXED  
PHASE:  VAPOR  
COMPONENTS: LB MOL/HR  
PROPANE  21.0380  
PROPANE  4186.5784  
HYDROGEN  0.0  
OXYGEN  0.0  
WATER  0.0  
CO  0.0  
CO2  0.0  
METHANE  0.0  
ETHANE  0.0  
ETHENE  0.0  
COMPONENTS: LB/HR  
PROPANE  927.7032  
PROPANE  1.7617+05  
HYDROGEN  0.0  
OXYGEN  0.0  
WATER  0.0  
CO  0.0  
CO2  0.0  
METHANE  0.0  
ETHANE  0.0  
ETHENE  0.0  

TOTAL FLOW:  
LB MOL/HR  4207.6164  
LB/HR  1.7710+05  
CUFT/HR  1.4412+05  

STATE VARIABLES:  
TEMP  F  338.2659  
PRES PSIA  250.0000  
VFRAC  1.0000  
LFRAC  0.0  
SFRAC  0.0  
ENTHALPY:  

~APFI11.tmp  

Page 47
BTU/LBMOL  1.3171e+04
BTU/LB    312.9268
BTU/HR    5.5420e+07
ENTROPY:
  BTU/LBMOL-R  -32.5596
  BTU/LB-R     -0.7736
DENSITY:
  LBMOL/CUFT  2.9195-02
  LB/CUFT     1.2289
  AVG Mw      42.0907

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

TEMP  F    338.2659
PRES  PSIA 250.0000
HFLMX BTU/HR 5.5420e+07

S310----

STREAM ID  S310
FROM    :  M801
TO      :  C301

SUBSTREAM: MIXED PHASE:

  COMPONENTS: LBMOL/HR
              PROPANE  2020.7447
              PROPENE  385.1691
              HYDROGEN  6.6292-05
              OXYGEN   0.0
              WATER    0.0
              CO       5.5859-04
              CO2      5.7303-02
              METHANE  1.9617-03
              ETHANE   0.2072
              ETHENE   7.0584-02

COMPONENTS: LB/HR

  PROPANE  8.9108e+04
  PROPENE  1.6208e+04
  HYDROGEN 1.3364-04
  OXYGEN   0.0
  WATER    0.0
  CO       1.6646-02
  CO2      2.5219
  METHANE  3.1472-02
  ETHANE   6.2314
  ETHENE   1.9802

TOTAL FLOW:

  LBMOL/HR  2406.2515
  LB/HR     1.0533e+05
  CUFT/HR   3.2185e+04

STATE VARIABLES:

  TEMP    F    257.0000
  PRES    PSIA 575.0000
  VFRAC   1.0000
  LFRAC   0.0
  SFRAC   0.0

ENTHALPY:

  BTU/LBMOL  -3.2902e+04
  BTU/LB     -751.6762
  BTU/HR     -7.9172e+07

~APF311.tmp
ENTROPY:
  BTU/LB MOL = R -60.2607
  BTU/LB = R -1.3767
DENSITY:
  LB MOL/CUFT 7.4764-02
  LB/CUFT 3.2726
  AVG MW 43.7721
MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
  TEMP F 257.0000
  PRES PSIA 575.0000
  HFLMX BTU/HR -7.9172+07
S311
=====
STREAM ID S311
FROM : C301
TO : MX301
SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LB MOL/HR
  PROPANE 2020.7447
  PROPENE 385.1691
  HYDROGEN 6.6292-05
  OXYGEN 0.0
  WATER 0.0
  CO 5.5859-04
  CO2 5.7303-02
  METHANE 1.9617-03
  ETHANE 0.2072
  ETHENE 7.0584-02
COMPONENTS: LB/HR
  PROPANE 8.9108+04
  PROPENE 1.6208+04
  HYDROGEN 1.3364-04
  OXYGEN 0.0
  WATER 0.0
  CO 1.5646-02
  CO2 2.5239
  METHANE 3.1472-02
  ETHANE 6.2314
  ETHENE 1.9802
TOTAL FLOW:
  LB MOL/HR 2406.2515
  LB/HR 1.0533+05
  CUFT/HR 7.3548+05
STATE VARIABLES:
  TEMP F 109.9772
  PRES PSIA 20.0000
  VFRACTION 1.0000
  LFRACTION 0.0
  SFRAC 0.0
ENTHALPY:
  BTU/LB MOL -3.5827+04
  BTU/LB -818.4816
  BTU/HR -8.6208+07
ENTROPY:
  BTU/LB MOL = R 58.1411
  BTU/LB = R -1.3283
DENSITY:
LB/MOL/CFUFT  3.2717-03
LB/CFUFT  0.1432
AVG MW  43.7721

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F  109.9772
PRES PSIA  20.0000
HFLIX BTU/HR  -8.6208+07

S312

STREAM ID  S312
FROM :  MX301
TO :  B1

SUBSTREAM: MIXED
PHASE:  MIXED
COMPONENTS: LB/MOL/HR
PROPANE  4822.3026
PROPENE  396.1219
HYDROGEN  6.6292-05
OXYGEN  0.0
WATER  21.6101
CO  5.5859-04
CO2  5.7393-02
METHANE  1.9617-03
ETHANE  0.2072
ETHENE  7.0584-02

COMPONENTS: LB/HR
PROPANE  2.1265+05
PROPENE  1.6669+04
HYDROGEN  1.3364-04
OXYGEN  0.0
WATER  389.3114
CO  1.5646-02
CO2  2.5219
METHANE  3.1472-02
ETHANE  6.2314
ETHENE  1.9802

TOTAL FLOW:
LB/MOL/HR  5.240.3723
LB/HR  2.2972+05
CUFT/HR  1.1278+06

STATE VARIABLES:
TEMP F  -28.8264
PRES PSIA  20.0000
VFRAC  0.9306
LFRAC  6.9396-02
SFRAO  0.0

ENTHALPY:
BTU/LB/MOL  -4.3507+04
BTU/LB  -992.5094
BTU/HR  -2.2800+08

ENTROPY:
BTU/LB/MOL-R  -66.7457
BTU/LB-`R  -1.5226

DENSITY:
LB/MOL/CFUFT  4.6465-03
LB/CFUFT  0.2037
AVG Mw 43.8358

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F -28.8264
PRES PSIA 20.0000
HFLMX BTU/HR -2.2800x08

S313

STREAM ID S313
FROM : H803
TO : C904

SUBSTREAM: MIXED
PHASE: VAPOR

COMPONENTS: LB/MOL/HR
PROPANE 4340.0723
PROPENE 356.5097
HYDROGEN 5.9663-05
OXYGEN 0.0
WATER 49.4491
CO 5.0273-04
CO2 5.1573-02
METHANE 1.7656-03
ETHANE 0.1865
ETHENE 6.3526-02

COMPONENTS: LB/HR
PROPANE 1.0138-05
PROPENE 1.5002x04
HYDROGEN 1.2027-04
OXYGEN 0.0
WATER 350.3802
CO 1.4082-02
CO2 2.2697
METHANE 2.8324-02
ETHANE 5.6082
ETHENE 1.7821

TOTAL FLOW:
LB/MOL/HR 4716.3350
LB/HR 2.0674x05
CUFT/HR 1.3445x06

STATE VARIABLES:
TEMP F 71.6000
PRES PSIA 20.0000
VFRAc 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:
BTU/LB/MOL -4.1282x04
BTU/LB -941.7967
BTU/HR -1.9470x08

ENTROPY:
BTU/LB/MOL-R -62.0035
BTU/LB-R -1.4144

DENSITY:
LB/MOL/CUFT 3.5080-03
LB/CUFT 0.1538
AVG Mw 43.8358

MIXED SUBSTREAM PROPERTIES:
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**STREAM ID** | S314  
**FROM** | C304  
**TO** | N3102  
**SUBSTREAM: MIXED**  
**PHASE:** | VAPOUR  
**COMPONENTS: LB MOL/HR**  
| **PROPANE** | 4340.0723  
| **PROPENE** | 366.5097  
| **HYDROGEN** | 5.9663E-05  
| **OXYGEN** | 0.0  
| **WATER** | 19.4491  
| **CO** | 5.0273E-04  
| **CO2** | 5.1573E-02  
| **METHANE** | 1.7656E-03  
| **ETHANE** | 0.1865  
| **ETHENE** | 6.3526E-02  
**COMPONENTS: LB/HR**  
| **PROPANE** | 1.9138E+05  
| **PROPENE** | 1.5002E+04  
| **HYDROGEN** | 1.2027E+04  
| **OXYGEN** | 0.0  
| **WATER** | 350.3802  
| **CO** | 1.4082E-02  
| **CO2** | 2.2697  
| **METHANE** | 2.8324E-02  
| **ETHANE** | 5.6082  
| **ETHENE** | 1.7821  
**TOTAL FLOW:**  
| **LB MOL/HR** | 4716.3350  
| **LB/HR** | 2.0674E+05  
| **CUFT/HR** | 4.4694E+05  
**STATE VARIABLES:**  
| **TEMP** | 180.7066  
| **PRES** | 72.5189  
| **VFRAC** | 1.0000  
| **LFRAC** | 0.0  
| **SFRAC** | 0.0  
**ENTHALPY:**  
| **BTU/LB MOL** | -3.9253E+04  
| **BTU/LB** | -895.4494  
| **BTU/HR** | -1.8513E+08  
**ENTROPY:**  
| **BTU/LB MOL-R** | -61.0957  
| **BTU/LB -R** | -1.3937  
**DENSITY:**  
| **LB MOL/CUFT** | 1.0553E-02  
| **LB/CUFT** | 0.4626  
| **AVG MW** | 43.8358  

**MIXED SUBSTREAM PROPERTIES:**  
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**S315**

**STREAM ID**

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**SUBSTREAM: MIXED**

**PHASE:** VAPOUR

**COMPONENTS: LB/MOL/HR**

| PROPANE | 21.0380 |
| PROPENE | 4186.5784 |
| HYDROGEN | 0.0 |
| OXYGEN | 0.0 |
| WATER | 0.0 |
| CO | 0.0 |
| CO2 | 0.0 |
| METHANE | 0.0 |
| ETHANE | 0.0 |
| ETHENE | 0.0 |

**COMPONENTS: LB/HR**

| PROPANE | 927.7032 |
| PROPENE | 1.7617E+05 |
| HYDROGEN | 0.0 |
| OXYGEN | 0.0 |
| WATER | 0.0 |
| CO | 0.0 |
| CO2 | 0.0 |
| METHANE | 0.0 |
| ETHANE | 0.0 |
| ETHENE | 0.0 |

**TOTAL FLOW:**

| LB/MOL/HR | 4207.6164 |
| LB/HR | 1.7710E+05 |
| CUFT/HR | 1.4203E+05 |

**STATE VARIABLES:**

| TEMP F | 326.7204 |
| PRES PSIA | 250.0000 |
| VFRAC | 1.0000 |
| LFRAC | 0.0 |
| SFRAC | 0.0 |

**ENTHALPY:**

| BTU/LB/MOL | 1.2934E+04 |
| BTU/LB | 307.2803 |
| BTU/HR | 5.4420E+07 |

**ENTROPY:**

| BTU/LB/MOL-R | -32.8596 |
| BTU/LB-R | -0.7807 |

**DENSITY:**

| LB/MOL/CUFT | 2.9624E-02 |
| LB/CUFT | 1.2469 |
| AVG MW | 42.0907 |

**MIXED SUBSTREAM PROPERTIES:**

*** ALL PHASES ***

| TEMP F | 326.7204 |
| PRES PSIA | 250.0000 |
| HFLMX BTU/HR | 5.4420E+07 |
STREAM ID: S316
FROM: M802
TO: ----

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LB/MOL/HR
PROPANE 21.0380
PROPENE 4186.5784
HYDROGEN 0.0
OXYGEN 0.0
WATER 0.0
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

COMPONENTS: LB/HR
PROPANE 927.7032
PROPENE 1.7617
HYDROGEN 0.0
OXYGEN 0.0
WATER 0.0
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

TOTAL FLOW:
LB/MOL/HR 4207.6164
LB/HR 1.7710
CUFT/HR 5849.6963

STATE VARIABLES:
TEMP F 100.0000
PRES PSIA 250.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
BTU/LB/MOL 3161.5962
BTU/LB 75.1139
BTU/HR 1.3303

ENTROPY:
BTU/LB/MOL-R -48.9159
BTU/LB-R -1.1622

DENSITY:
LB/CUFT 30.2759

AVG MW 42.0907

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 100.0000
PRES PSIA 250.0000
HFLX BTU/HR 1.3303
SAFETY DATA SHEET
Version 5.3
Revision Date 02/03/2014
Print Date 04/01/2016

1. PRODUCT AND COMPANY IDENTIFICATION
1.1 Product identifiers
Product name: 2-Methylimidazole
Product Number: M90660
Brand: Alkali
CAS No.: 689-96-1

1.2 Relevant identified uses of the substance or mixture and uses advised against
Identified uses: Laboratory chemicals. Manufacture of substances

1.3 Details of the supplier of the safety data sheet
Company: Sigma-Aldrich
3501 Spruce Street
SAINT LOUIS MO 63103
USA
Telephone: +1 800-325-5532
Fax: +1 800-325-5562

1.4 Emergency telephone number
Emergency Telephone: (314) 776-6555

2. HAZARDS IDENTIFICATION
2.1 Classification of the substance or mixture
GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Acute toxicity, Oral (Category 4), H302
Skin corrosion (Category 1B), H314
Serious eye damage (Category 1), H318

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

2.2 GHS Label elements, including precautionary statements
Picture
Signal word: Danger
Hazard statement(s): Harmful if swallowed.
Causes severe skin burns and eye damage.
Precautionary statement(s):
P230 Do not breathe dust or mist.
P264 Wash skin thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.
P280 Wear protective gloves/protective clothing/eye protection/face protection.
P301 + P332 IF SWALLOWED: Call a POISON CENTER or doctor/physician if you feel unwell.
P302 + P352 + P331 IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P303 + P361 + P353 IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P310 Immediately call a POISON CENTER or doctor/physician.
P311 Specific treatment (see supplemental first aid instructions on this label).
P303 Wash contaminated clothing before reuse.
P406 Store locked up.
P501 Dispose of contents/container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (H304) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS
3.1 Substances
Synonyms: 2-Methylpyrazine
Formula: C8H9N2
Molecular Weight: 149.19 g/mol
CAS No.: 689-96-1
EC-No.: 217-765-7

Hazardous components
Component: 2-Methylimidazole
Classification: Acute Tox. 4, Skin Corr. 1B, Eye Dam. 1, H302, H314
Concentration: 80 - 100 %

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

4. FIRST-AID MEASURES
4.1 Description of first aid measures
General advice: Consult a physician. Show this safety data sheet to the doctor in attendance. Move out of dangerous area.
If inhaled: If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.
In case of skin contact: Take off contaminated clothing and shoes immediately. Wash off with soap and plenty of water. Consult a physician.
In case of eye contact: Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician. Continue rinsing eyes until hospital.
If swallowed: Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

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

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

5. FIREFIGHTING MEASURES
5.1 Extinguishing media
Suitable extinguishing media: Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Alkali - M90660
Page 1 of 8

Alkali - M90660
Page 2 of 8

Appendix C: Material Safety Data Sheets
5.2 Special hazard arising from the substance or mixture
Carbon oxides, nitrogen oxides (NOx)

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

5.4 Further information
No data available.

5. ACCIDENTAL RELEASE MEASURES

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

5.2 Environmental precautions
Do not let product enter drains.

5.3 Methods and materials for containment and cleaning-up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

5.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Introduce appropriate exhaust ventilation at places where dust is formed. For precautions see section 2.2.

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

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

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters
Components with workplace control parameters
Contain no substances with occupational exposure limit values.

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

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

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

Full contact
Material: nitrile rubber
Minimum layer thickness: 0.11 mm
Tear strength: 480 mm

Material tested: Diemat NW (KCL 740 / Aldrich Z677372, Size M)
Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Tear strength: 480 mm
Material tested: Diemat NW (KCL 740 / Aldrich Z677372, Size M)

data sources: KOL GmbH D-38124 Eisenach; phone +49 (0) 5659-8700; e-mail sales@kcl.de; test method: EN 374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body protection
Complete wall protecting against chemicals. This type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CE (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance
   - Form: powder
b) Odour
   - no data available
c) Odour threshold
   - no data available
d) pH
   - no data available
e) Vapour pressure
   - boiling range: 142 - 143 °C (284 - 295 °F) - lit.
f) Initial boiling point
   - 267 - 268 °C (514 - 514 °F) - lit.
g) Flash point
   - no data available
h) Evaporation rate
   - no data available
i) Flammability (solid, gas)
   - no data available
j) Upper/lower flammability limits
   - no data available
k) Vapour density
   - no data available
l) Relative density
   - no data available
m) Water solubility
   - no data available
n) Partition coefficient n-octanol/water
   - no data available
p) Auto-ignition temperature
   - no data available
q) Decomposition temperature
   - no data available
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MATERIAL SAFETY DATA SHEET
Activated Carbon

Section 01 - Chemical and Product and Company Information

Product Information
Activated carbon (All Grades)
Product Use
Water purification, gold recovery, and air scrubbing

Supplier Name
ClearTech Industries Inc.
350 Quintet Avenue
Saskatoon, SK, Canada
S7K 0N7

Prepared By
ClearTech Industries Inc. Technical Department
Phone: 1-800-367-7503
Preparation Date
February 10, 2009
24-Hour Emergency Phone
1-800-367-7503

Section 02 - Composition / Information on Ingredients

Hazardous Ingredients
Activated Carbon 100%

CAS Number
Activated Carbon 7440-44-9

Synonyms
Activated granular carbon, activated powdered carbon, pellets activated carbon, activated charcoal, animal bone black.

Section 03 - Hazard Identification

Inhalation
Non-toxic through inhalation
Skin Contact / Absorption
Not Available
Eye Contact
Mechanical dust inhalation
Ingestion
Non-toxic through ingestion
Exposure Limits
OSHAPEL5: 5mg/m³ as resp.
ACGIH TLV: 10mg/m³ as total

Section 15 - Regulatory Information
SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.
SARA 303 Components
SARA 303: This material does not contain any chemicals with known CAS numbers exceeding the threshold (200 tons) reporting levels established by SARA Title III, Section 303.
SARA 510/1502 Hazards
Acute Health Hazard, Chronic Health Hazard
Massachusetts Right To Know Components
No components are subject to the Massachusetts Right To Know Act.
Pennsylvania Right To Know Components
2-Methylimidazole CAS-No. 693-95-1
New Jersey Right To Know Components
2-Methylimidazole CAS-No. 693-95-1
California Prop. 65 Components
This product contains a chemical known to the State of California to cause cancer CAS-No. 693-95-1

Section 16 - Other Information
Full list of Ms-Statements referred to under sections 2 and 3.

Further Information
Copyright 2014 Sigma-Aldrich Co. LLC. License granted to make unlimited paper copies for internal use only. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handing or from contact with the above product. See our sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.
Section 06 - Accidental Release Measures

Leak / Spill

Wear appropriate personal protective equipment. Ventilate area. Stop or reduce leak if safe to do so. Prevent material from entering sewers. Vacuum or shovel spilled material and place in closed container for proper disposal.

Deactivating Materials

Not Available

Section 07 - Handling and Storage

Handling Procedures

Use proper equipment for lifting and transporting all containers. Use sensible industrial hygiene and housekeeping practices. Wash thoroughly after handling. Avoid all situations that could lead to harmful exposure.

Storage Requirements

Store in a clean, well-ventilated area away from oxidizers, acids, ignition sources, heat and combustible materials.

Section 08 - Personal Protection and Exposure Controls

Protective Equipment

Eyes

Chemical goggles, full-face shield, or a full-face respirator is to be worn at all times when product is handled. Contact lenses should not be worn; they may contribute to severe eye injury.

Respiratory

Respiratory protection is not normally required. If use creates dust formations, then a NIOSH-approved respirator with a dust cartridge is recommended. Wet activated carbon removes oxygen from air causing a severe hazard to workers inside confined spaces. Before entering such an area, sampling and work procedures for low oxygen levels should be planned (such as wearing a self-contained breathing apparatus).

Gloves

Impervious gloves of chemically resistant material (rubber or PVC) should be worn. Wash contaminated clothing and dry thoroughly before reuse.

Clothing

Suits, aprons, and/or coversalls of chemically resistant material should be worn at all times. Wash contaminated clothing and dry thoroughly before reuse.

Footwear

No special footwear is required other than what is mandated at place of work.

Other

Not Available

Section 04 - First Aid Measures

Inhalation

Remove victim to fresh air. Give artificial respiration only if breathing has stopped. If breathing is difficult, give oxygen. Seek medical attention.

Skin Contact / Absorption

Remove contaminated clothing. Wash affected area with soap and water. Seek medical attention if irritation occurs or persists.

Eye Contact

Flush immediately with water for at least 20 minutes. Forbide eyelids apart to ensure complete irrigation of eye tissue. Seek medical attention.

Ingestion

No known health effects. Seek medical attention if any problems are experienced.

Additional Information

Not Available

Section 05 - Fire Fighting

Conditions of Flammability

Non-flammable under normal circumstances. Once ignited, the fire generally burns evenly (smoldering) with a dull glow and may be difficult to detect.

Means of Extinction

Use water spray, alcohol foam, dry chemical or carbon dioxide.

Flash Point

Not Applicable

Auto-Ignition Temperature

> 220°C

Upper Flammable Limit

Not Applicable

Lower Flammable Limit

Not Applicable

Hazardous Combustible Products

Carbon monoxide, formaldehyde, and carbon dioxide. Contact with strong oxidizers (ozone). Metal coppers may cause rapid combustion.

Special Fire Fighting Procedures

Wear NIOSH approved self-contained breathing apparatus and protective clothing.

Explosion Hazards

Airborne dust may create an explosion hazard.
Section 10 - Stability and Reactivity

Stability: Stable under normal conditions.
Incompatibility: Strong oxidizers such as ozone, liquid oxygen, chlorine, potassium permanganate.

Hazardous Products of Decomposition: Carbon monoxide may be generated in the event of a fire, especially with incomplete combustion in an enclosed space.
Polymerization: Will not occur.

Section 11 - Toxicological Information

Irritancy: Not Available
Sensitization: Not Available
Chronic/Acute Effects: Not Available
Synergistic Effects: Not Available

Animal Toxicity Data:
LD₅₀ (oral, rat): >15 g/kg
LD₅₀ (inhalation): >64.4 mg/L

Carcinogenicity: Not considered to be carcinogenic as per IARC, NTP, and OSHA.
Reproductive Toxicity: Not Available
Teratogenicity: Not Available
Mutagenicity: Not Available

Section 12 - Ecological Information

Fish Toxicity: Not Available
Biodegradability: Not Available
Environmental Effects: Not Available

Section 09 - Physical and Chemical Properties

Physical State: Solid
Odor and Appearance: Black odourless particulate solid, pellet, or powder
Odor Threshold: Not Available
Specific Gravity (Water = 1): 0.25 – 0.80
Vapor Pressure (mm Hg, 20°C): Not Available
Vapor Density (Air = 1): Not Available
Evaporation Rate: Not Available
Boiling Point: Maximum 400°C
Freeze/Melting Point: >350°C
pH: Not Available
Water/Oil Distribution Coefficient: Not Available
Bulk Density: >400 g/L
% Volatiles by Volume: 0%
Solubility in Water: Insoluble

Molecular Formula: C
Molecular Weight: 12.011
### ClearTech Industries Inc. - Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Address</th>
<th>Postal Code</th>
<th>Phone Number</th>
<th>Fax Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richmond, B.C.</td>
<td>12431 Government Way</td>
<td>V4A 4X8</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
<tr>
<td>Port Coquitlam, B.C.</td>
<td>5225 Kingsway Ave</td>
<td>V3C 1H2</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
<tr>
<td>Calgary, AB</td>
<td>6400 - 47th St.</td>
<td>T2G 2E1</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
<tr>
<td>Edmonton, AB</td>
<td>11750 - 183rd Ave.</td>
<td>T6E 0A9</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
<tr>
<td>Saskatoon, SK</td>
<td>2502 Harbord Avenue</td>
<td>S7L 4V3</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
<tr>
<td>Regina, SK</td>
<td>550 Bannock Drive</td>
<td>S4T 2X3</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
<tr>
<td>Winnipeg, MB</td>
<td>340 Guildford Crescent</td>
<td>R3T 2T1</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
<tr>
<td>Montreal, ON</td>
<td>7400 Bath Road</td>
<td>H4P 3L2</td>
<td>(860) 387-7500</td>
<td>1-860-387-7500</td>
</tr>
</tbody>
</table>

24 Hour Emergency Number - All Locations – 1 (860) 387-7500

---

### Section 13 - Disposal Considerations

**Waste Disposal**

Dispose in accordance with all federal, provincial, and/or local regulations including the Canadian Environmental Protection Act.

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### Section 14 - Transportation Information

**TDG Classification**

Class: Not regulated

Group: Not regulated

PIN Number: Not regulated

Other: Secure containers (full and/or empty) with suitable hold down devices during shipment.

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### Section 15 - Regulatory Information

**WHMIS Classification**

Not a controlled product

Revision Date: December 19, 2013

**NOTE:** The product listed on this MSDS has been classified in accordance with the hazard criteria of the Canadian Controlled Products Regulations. This MSDS contains all information required by these regulations.

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### Section 16 - Other Information

**Note:** The responsibility to provide a safe workplace remains with the user. The user should consider the health hazards and safety information contained herein as a guide and should take those precautions required in an individual operation to protect employees and develop safe practice procedures for a safe work environment. The information contained herein is, to the best of our knowledge and belief, accurate. However, since the conditions of handling and use are beyond our control, we make no guarantee of results, and assume no liability for damages incurred by the use of this material. It is the responsibility of the user to comply with all applicable laws and regulations.

**Attention:** Recipient of the chemical goods MSDS coordinator

As part of our commitment to the Canadian Association of Chemical Distributors (CADC) Responsible Distribution® initiative, ClearTech Industries Inc. and its associated companies require, as a condition of sale, that you forward the attached Material Safety Data Sheets (MSDS) to all affected employees, customers, and end-users. ClearTech will send any available supplementary handling, health, and safety information to you at your request.

If you have any questions or concerns please call our customer service or technical service department.
SECTION 4. FIRST AID

INHALATION: Persons suffering from overexposure should be moved to fresh air. If victim is not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.

EYE CONTACT: Contact with liquid or cold vapor can cause freezing of tissue. Gently flush eyes with lukewarm water. Obtain medical attention immediately.

SKIN CONTACT: Contact with liquid or cold vapor can cause frostbite. Immediately warm affected area with lukewarm water not to exceed 105 °F.

NOTES TO PHYSICIAN: There is no specific treatment. Treatment for overexposure should be directed at the control of symptoms and the clinical condition.

SECTION 5. FIRE AND EXPLOSION

FLASH POINT: Not Applicable

AUTOIGNITION: Nonflammable

FLAMMABLE LIMITS: Nonflammable

EXTINGUISHING MEDIA: Carbon dioxide is nonflammable and does not support combustion. Carbon dioxide is an extinguishing agent for class B and C fires. Use extinguishing media appropriate for the surrounding fire.

HAZARDOUS COMBUSTION PRODUCTS: None known.

FIRE FIGHTING PROCEDURES: Evacuate personnel from danger area. Carbon dioxide is nonflammable. If possible, without risk, remove cylinders from fire area or cool with water. Self contained breathing apparatus (SCBA) may be required for rescue workers.

UNUSUAL HAZARDS: Upper exposure to intense heat or flame, cylinder will vent rapidly and rupture violently. Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a container can build up due to heat and it may rupture if pressure relief devices fail to function.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Evacuate all personnel from affected area. Increase ventilation to release area and monitor oxygen levels. Use appropriate protective equipment (SCBA). If leak is from cylinder or cylinder valve call the Air Products emergency telephone number. If leak is in user’s system close cylinder valve and vent pressure before attempting repairs.

SECTION 3. HANDLING AND STORAGE

STORAGE: Cylinders should be stored upright in a well-ventilated, secure area protected from the weather. Storage area temperatures should not exceed 125 °F (52 °C). Storage should be away from heavily traveled areas and emergency exits. Avoid areas where salt or other corrosive materials are present. Valve protection caps and valve outlet seats should remain on cylinders not connected for use. Separate full and empty cylinders. Avoid excessive inventory and storage time. Use a first-in-first-out system. Keep good inventory records.

HANDLING: Use a suitable hand truck for cylinder movement. Never attempt to lift a cylinder by its valve protection valve cap. Never apply flame or localized heat directly to any part of the cylinder. Do not

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

CONCENTRATION: Carbon dioxide is sold as pure product > 99%.

CAS NUMBER: 124-38-9

EXPOSURE LIMITS: OSHA: PEL-TWA = 5000 ppm ACGIH: TLV-TWA = 5000 ppm NIOSH: None established

SECTION 3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
Carbon dioxide is a nonflammable liquefied compressed gas packaged in cylinders under its own vapor pressure of 635 psig at 70 °F (21.1 °C). High concentrations can cause rapid asphyxiation and can also increase respiration and heart rate. Contact with liquid may cause frostbite. Avoid breathing gas. Self contained breathing apparatus (SCBA) may be required by rescue workers.

EMERGENCY TELEPHONE NUMBERS
800 - 523-9374 Continental U.S., Canada, or Puerto Rico
610 - 461-7711 other locations

POTENTIAL HEALTH EFFECTS:
INHALATION: Carbon dioxide is an asphyxiant. Concentrations of 10% or more can produce unconsciousness or death.

EYE CONTACT: Contact with liquid or cold vapor can cause freezing of tissue.

SKIN CONTACT: Contact with liquid or cold vapor can cause frostbite.

EXPOSURE INFORMATION:
ROUTE OF ENTRY: Inhalation

TARGET ORGANS: Central nervous system

EFFECT: Asphyxiation (suffocation). Overexposure may cause damage to renal ganglion cells and central nervous system.
SECTION 10. STABILITY AND REACTIVITY
STABILITY: Stable
CONDITIONS TO AVOID: None
INCOMPATIBILITY (Materials to Avoid): None
REACTIVITY: None
HAZARDOUS DECOMPOSITION PRODUCTS: None
HAZARDOUS POLYMERIZATION: Will not occur

SECTION 11. TOXICOLOGICAL INFORMATION
Carbon dioxide is an asphyxiant. It initially stimulates respiration and then causes respiratory depression. High concentrations result in narcosis. Symptoms in humans are as follows:

<table>
<thead>
<tr>
<th>CONCENTRATION</th>
<th>EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>Slight increase in breathing rate</td>
</tr>
<tr>
<td>2%</td>
<td>Breathing rate increases to 50% above normal. Prolonged exposure can cause headache and tiredness.</td>
</tr>
<tr>
<td>3%</td>
<td>Breathing increases to twice the normal rate and becomes labored. Weak narcotic effect. Impaired hearing, headache, increase in blood pressure and pulse rate.</td>
</tr>
<tr>
<td>4-5%</td>
<td>Breathing increases to approximately four times the normal rate, symptoms of intoxication become evident and slight shivering may be felt.</td>
</tr>
<tr>
<td>5-10%</td>
<td>Characteristic sharp odor noticeable. Very labor breathing, headache, visual impairment and ringing in the ears. Judgement may be impaired, followed by drowsiness and loss of consciousness.</td>
</tr>
<tr>
<td>50-100%</td>
<td>Unconsciousness occurs more rapidly above 10% level. Prolonged exposure to high concentrations may eventually result in death from asphyxiation.</td>
</tr>
</tbody>
</table>

SECTION 12. ECOLOGICAL INFORMATION
No adverse ecological effects are expected. No adverse ecological effects are expected. Carbon dioxide does not contain any Class I or Class II ozone depleting chemicals. Carbon dioxide is not labeled as a marine pollutant by DOT (49 CFR 171).

SECTION 13. DISPOSAL
UNUSED PRODUCT / EMPTY CYLINDER: Return cylinder and unused product to supplier. Do not attempt to dispose of unused product. Ensure cylinder valve is properly closed, valve outlet cap has been reinstalled, and valve protection cap is secured before shipping cylinder.

VAPE METHODS: For emergency disposal, secure the cylinder and slowly discharge gas to the atmosphere in a well ventilated area or outdoors. Small amounts may be disposed of by reacting with a mild base.

SECTION 14. TRANSPORT INFORMATION
DOT SHIPING NAME: Carbon dioxide
HAZARD CLASS: 2.2 (Nonflammable Gas)
IDENTIFICATION NUMBER: UN1013

allow any part of the cylinder to exceed 125 °F (52 °C). High temperature may cause damage to cylinder and/or premature failure of pressure relief device which will result in venting of cylinder contents. If user experiences any difficulty operating cylinder valve disconnect use and contact supplier. Never insert an object (e.g., wrench, screwdriver, pry bar, etc.) into valve cap openings. Doing so may damage valve causing a leak to occur. Use an adjustable wrench to remove overtight or rusted caps.

Only the proper CO2 connections should be used, never use adapters. Use piling and equipment adequately designed to withstand pressures to be encountered. If liquid product is being used ensure steps have been taken to prevent entrapment of liquid in closed systems. The use of pressure relief devices may be necessary. Use a check valve or other protective apparatus in any line or piling from the cylinder to prevent reverse flow.

Carbon dioxide is compatible with all common materials of construction. Pressure requirements should be considered when selecting materials and designing systems.

Use a "FULL", "IN USE", and "EMPTY" tag system on cylinders. This will reduce the chances of inadvertently connecting or operating the wrong cylinder.

SPECIAL REQUIREMENTS: Always store and handle compressed gases in accordance with Compressed Gas Association, Inc. (pbd: 703-978-0700) pamphlet CGA P-1, Safe Handling of Compressed Gases in Containers. Local regulations may require specific equipment for storage or use.

CAUTION: Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Disposal of a compressed gas cylinder which has not been filled by the owner or with the owner's written consent is a violation of federal law.

SECTION 5. PERSONAL PROTECTION / EXPOSURE CONTROL
ENGINEERING CONTROLS: Provide ventilation and/or local exhaust to prevent accumulation of carbon dioxide concentrations above 5000 ppm.

RESPIRATORY PROTECTION: Emergency Use: Self contained breathing apparatus (SCBA) or positive pressure airline with mask and escape pack are to be used in oxygen deficient atmosphere. Air purifying respirators will not provide protection.

EYE PROTECTION: Safety glasses are recommended when handling, connecting, or disassembling cylinders, and when pressurizing systems.

OTHER PROTECTIVE EQUIPMENT: Safety shoes and leather work gloves when handling cylinders.

SECTION 3. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, ODOR AND STATE: Colorless and odorless. A slightly acid gas. It is felt by some to have a slight pungent odor and biting taste.

MOLECULAR WEIGHT: 44.01

GAS DENSITY (at 70 °F (21.1 °C) and 1 atm): 0.1144 lb/ft³ (1.523 kg/m³)

VAPOR PRESSURE (at 70 °F (21.1 °C)): 838 psig

SPECIFIC GRAVITY (air=1): 1.523

SPECIFIC VOLUME (at 70 °F (21.1 °C) and 1 atm): 8.74 ft³/lb (5.457 m³/kg)

BOILING POINT: -100 °F (-78.5 °C)

TRIPLE POINT (at 68 psig): -56.9 °F (-48.8 °C)

SOLUBILITY IN WATER (Vol/Vol at 68 °F (20 °C)): 0.90
SAFETY DATA SHEET
Carbon Monoxide

Section 1. Identification

GHS product identifier: Carbon Monoxide
Chemical name: carbon monoxide
Other means of identification: Carbon monoxide (CO); CO, Exhaust gas; Flue gas; Carbonic oxide; Carbon dioxide; Oxynitride; Nitric oxide; N2O; Oxide of carbon; UN 1910; Wiegla faren; Carbon monoxide.

Synonym: Carbon monoxide (CO); CO, Exhaust gas; Flue gas; Carbonic oxide; Carbon dioxide; Oxynitride; Nitric oxide; N2O; Oxide of carbon; UN 1910; Wiegla faren; Carbon monoxide.

SOS # 023214
Supplier's details: Airgas USA, LLC and its affiliates 292 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5269 1-810-667-5253

Emergency telephone number (with hours of operation) 1-800-734-3430

Section 2. Hazards identification

OSHA/ICS 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 - ACUTE TOXICITY (Inhalation) - Category 1 - TOXIC TO REPRODUCTION (Fertility) - Category 1 - TOXIC TO REPRODUCTION (Sperm-DNA) - Category 1 - SPECIFIC TARGET ORGAN TOXICITY (REPEATED EXPOSURE) - Category 1

GHS label elements: None

Signal word: Danger
Hazard statements: Extremely flammable gas. May form explosive mixtures with air. Contains gas under pressure; may explode if heated. Asphyxiating even with adequate oxygen. May become incendiary. May damage fertility or the unborn child. Causes damage to organs through prolonged or repeated exposure.

Precautionary statements: None

Date of issue/Dated of revision: 04/12/2015
Date of previous issue: 07/12/2015
Version: 6.07

PRODUCT RQ: None
SHIPPING LABEL(s): Nonflammable gas
PLACARD (when required): Nonflammable gas
SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure upright position in a well-ventilated truck. Never transport in passenger compartment of a vehicle.

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

ENVIRONMENTAL PROTECTION AGENCY (EPA):

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980 requires notification to the National Response Center of a release of quantities of hazardous substances equal to or greater than the reportable quantities (RQ's) in 40 CFR 302.4.
CERCLA Reportable Quantity: None.

SARA TITLE III: Superfund Amendment and Reauthorization Act of 1986
SECTION 302/304: Requires emergency planning on threshold planning quantities (TPQ) and release reporting based on reportable quantities (RQ) of EPA's extremely hazardous substances (40 CFR 355).
Extremely Hazardous Substances: None
Threshold Planning Quantity (TPQ): None

SECTIONS 311/312: Require submission of material safety data sheets (MSDS) and chemical inventory reporting with identification of EPA's extremely hazardous substances. The hazard classes for this product are:
IMMEDIATE HEALTH: Yes
PRESSURE: Yes
DELAYED HEALTH: No
REACTIVITY: No
FLAMMABLE: No

SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR 372.
Carbon dioxide does not require reporting under Section 313.

40 CFR Part 68 - Risk Management Program for Chemical Accident Release Prevention: Requires the development and implementation of risk management programs at facilities that manufacture, use, store, or otherwise handle regulated substances in quantities that exceed specified thresholds.
Carbon dioxide is not listed as a regulated substance.

TSCA - TOXIC SUBSTANCES CONTROL ACT: Carbon dioxide is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

Carbon dioxide is not listed in Appendix A as a highly hazardous chemical.

STATE REGULATIONS:

CALIFORNIA:
Proposition 65: This product does NOT contain any listed substances which the State of California requires warning under this statute.
SCAQMD Rule: VOC = not applicable
Section 4. First aid measures

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

Skin contact: Wash contaminated skin with plenty of water. Remove any contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, use contaminated clothing thoroughly with water before removing it. Continue to rinse for at least 15 minutes. Get medical attention. Wash clothing before reuse. Clean shoes thoroughly before reuse.

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

Most important symptoms/effects, acute and delayed

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

Inhalation: Toxic if inhaled.

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

Frostbite: Try to warm up the frozen tissue 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: Adverse symptoms may include the following: reduced vital weight, increase in vital weight, skeletal deformities.

Skin contact: Adverse symptoms may include the following: reduced vital weight, increase in vital weight, skeletal deformities.

Ingestion: Adverse symptoms may include the following: reduced vital weight, increase in vital weight, skeletal deformities.

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

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

Specific treatments: No specific treatment.

Protection of first-aiders: No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Wash contaminated clothing thoroughly with water before removing it, or wear gloves.

See toxicological information (Section 11)

Section 3. Composition/information on ingredients

Substance/mixture: Substance

Chemical name: Carbon monoxide

Other means of identification: Carbon (amine, aldehydes, amine, aldehyde, tetracycline, Giuliani, N-2020, Orpyde de carbon, UH1016, Wegiel, nikkol, Carbon monoxide)

CAS number/other identifiers: 630-08-0

Product code: 63014

Ingredient name: Carbon monoxide % CAS number

100 630-08-0

There are no additional ingredients present which, with the current knowledge of the supplier and the in the concentrations applicable, are identified 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

Immediate 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.
Section 6: Accident prevention measures

- Ensure that all personnel involved in the project are trained in accident prevention measures and are aware of the hazards associated with the work.
- Implement a system for reporting accidents and near misses.
- Regularly review and update the accident prevention measures to address any new hazards or changes in the project.

Section 7: Handling and storage

- Store all hazardous materials in a separate area, away from other materials.
- Use appropriate labels and warning signs to indicate the hazards of the materials.
- Ensure that all personnel handling the materials are provided with appropriate personal protective equipment.
- Implement a system for disposal of hazardous materials that complies with all relevant regulations.
Section 9. Physical and chemical properties

Burning rate: Not applicable.
Evaporation rate: Not available.
Flammability (solid, gas): Extremely flammable in the presence of the following materials or conditions: open flames, sparks and static discharge and existing materials.
Lower and upper explosive limits (flammable limits): Lower: 10.9%. Upper: 74.2%.
Vapor pressure: Not available.
Specific Volume (at 1atm): 13.593.
Gas Density (dry 20°C): 0.072.
Relative density: Not applicable.
Solubility: Not available.
Solubility in water: Not available.
Partition coefficient n-octanol/water: Not available.
Auto-ignition temperature: 607°C (1124.6°F).
Decomposition temperature: Not available.
SAYD: Not available.
Viscosity: Not applicable.

Section 10. Stability and reactivity

Reactivity: No specific test data related to reactivity available for this product or its ingredients.
Chemical stability: The product is stable.
Possibility of hazardous reactions: Under normal conditions of storage and use, hazardous reactions will not occur.
Conditions to avoid: Avoid all possible sources of ignition (spark or flame). Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition.
Incompatibility with various substances: Extremely reactive or incompatible with the following materials: oxidizing materials.

Hazardous decomposition products: Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization: Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects
Acute toxicity
Product/ingredient name: Carbon monoxide.
Route: LC50 Inhalation Gas.
Species: Rat.
Dose: 5780 ppm.
Exposure: 1 hour.

Environmental exposure controls:
Environments from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or ducting/enclosures to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures
Hygiene measures: Wash hands, forearms and face thoroughly after handling chemical products. Before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before repeating. Ensure that eyewash stations and safety showers are close to the workplace location.
Eye/face protection: Safety eyewear complying with an approved standard should be used when a risk assessment indicates it is necessary to avoid exposure to liquid splashes, mist, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.
Skin protection: Hand protection: Chemical-resistant, impervious, gloves complying with an approved standard should be worn at all times when handling chemical products. A risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still providing their protective properties. It should be noted that this time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures containing several substances, the protection time of the gloves cannot be accurately estimated.
Body protection: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product. When there is a risk of ignition from static electricity, wear anti-static protective clothing. For the greatest protection from static discharges, clothing should include anti-static overalls, boots and gloves.
Other skin protection: Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection: Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the self working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance
Physical state: Gas. [MAK BE A LIQUID AT LOW TEMPERATURE OR HIGH PRESSURE.]
Color: Colorless.
Molecular weight: 28.01 g/mole.
Molecular formula: CO.
Boiling/condensation point: 94.9°C (-132.7°F).
Melting/freezing point: -211.6°C (-349.8°F).
Critical temperature: 140.5°C (220.3°F).
Odor: Odorless.
Odor threshold: Not available.
pH: Not available.
Flash point: Not available.

Date of issue/Date of revision: 01/02/2015. Date of previous issue: 01/02/2013. Version: 0.07.
Section 11. Toxicological information

Potential immediate effects:
- Not available.

Potential delayed effects:
- Not available.

Long term exposure:
- Not available.

Potential immediate effects:
- Not available.

Potential delayed effects:
- Not available.

Potential chronic health effects:
- Not available.
  - General: Causes damage to organs through prolonged or repeated exposure.
  - Carcinogenicity: No known significant effects or critical hazards.
  - Mutagenicity: No known significant effects or critical hazards.
  - Teratogenicity: May damage the unborn child.
  - Developmental effects: No known significant effects or critical hazards.
  - Fertility effects: May damage fertility.

Numerical measures of toxicity:
- Acute toxicity estimates:
  - Not available.

Section 12. Ecological information

Toxicity:
- Not available.

Persistence and degradability:
- Not available.

Bioaccumulative potential:
- Not available.

Mobility in soil:
- Soil-water partition coefficient (Koc): Not available.

Other adverse effects:
- No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods:
- The generation of waste should be avoided or minimised whenever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any local authority requirements. Disposal of surplus and non-conform products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer system or as specified by local authorities with jurisdiction. Empty Arugas-owned pressure vessels should be returned to Arugas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is.

Date of issue/Date of revision:
- 01/12/2015
- 03/12/2015
- 05/12/2015
- 07/12/2015

Version: 0.07

Powered by HIS
Section 15. Regulatory information

Clean Air Act Section 602, Class II Substances
- Not listed

DEA List I (Chemicals (Precursor Chemicals)
- Not listed

DEA List II (Chemicals (Essential Chemicals)
- Not listed

SARA 302/304

Composition/Information on ingredients
No products were found.

SARA 313 RQ
- Not applicable.

SARA 311/312
- Fire hazard
-绰江 release of pressure
- Immediate (acute) health hazard

Delayed (chronic) health hazard

Composition/Information on ingredients

<table>
<thead>
<tr>
<th>Name</th>
<th>%</th>
<th>Fire hazard</th>
<th>Sudden release of pressure</th>
<th>Reactive</th>
<th>Immediate (acute) health hazard</th>
<th>Delayed (chronic) health hazard</th>
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</thead>
<tbody>
<tr>
<td>carbon monoxide</td>
<td>100</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

State regulations

Massachusetts
- This material is listed.

New York
- This material is not listed.

New Jersey
- This material is listed.

Pennsylvania
- This material is listed.

California Prop 65
- WARNING: This product contains a chemical known to the State of California to cause cancer, birth defects or other reproductive harm.

Ingredient name
- Cancer
- Reproductive
- No significant risk level
- Maximum acceptable dosage level

<table>
<thead>
<tr>
<th>Name</th>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Canada regulations
- This material is listed or exempted.

International regulations

Australia: Inflammable
- This material is listed or exempted.

China: Inflammable
- This material is listed or exempted.

Japan: Inflammable
- This material is listed or exempted.

Korea: Inflammable
- This material is listed or exempted.

New Zealand: Inflammable
- This material is listed or exempted.

Philippines: Inflammable
- This material is listed or exempted.

Taiwan: Inflammable
- This material is listed or exempted.

Chemical Weapons Convention List Schedule I: Chemicals
- Not listed

Section 13. Disposal considerations

This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residue. Do not puncture or incinerate container.

Section 14. Transport information

<table>
<thead>
<tr>
<th>UN number</th>
<th>DOT</th>
<th>TDG</th>
<th>Mexico</th>
<th>IMDG</th>
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<td>2.3 (2)</td>
<td>2.3 (2)</td>
</tr>
</tbody>
</table>

Packaging group
- -

Environment
- -

Additional information

“Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product.”

Special precautions for user
- Transport within user’s premises; always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code
- Not available.

Section 15. Regulatory information

United States regulations

TSCA (Toxics Substances Control Act)
- Not listed

Clean Air Act Section 112
- Not listed

(B) Hazardous Air Pollutants (HAPs)
- Clean Air Act Section 602
- Class I Substances
- Not listed

Date of issue: 1/1/2015

Date of previous issue: 1/1/2015

Version: 0.07
Section 15. Regulatory information

Chemical Weapons
Conventions
List Schedule
II Chemicals
Chemical Weapons
Conventions
List Schedule
II Chemicals

Canada
HMIS (Canada)
Class A: Compressed gas.
Class B: Flammable gas.
Class C: Material causing immediate and serious toxic effects (Very toxic).
Class D: Material causing other toxic effects (Very toxic).
CEPA Toxic substances: This material is not listed.
Canadian AER: This material is not listed.
Canadian HPR: This material is not listed.
Alberta Designated Substances: This material is not listed.
Ontario Designated Substances: This material is not listed.
Quebec Designated Substances: This material is not listed.

Section 16. Other information

Canada Label requirements
Class A: Compressed gas.
Class B: Flammable gas.
Class C: Material causing immediate and serious toxic effects (Very toxic).
Class D: Material causing other toxic effects (Very toxic).

Hazardous Material Information System (U.S.A.)

| Health | 1 |
| Flammability | 4 |
| Physical Hazard | 3 |

Caution: HMIS ratings are based on a 4-rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS ratings are not required on SDSs under 29 CFR 1910.1200, the user may choose to provide them. HMIS ratings are to be used with a fully-implemented HMIS program. HMIS ratings are available online at www.nfpa.org.

The customer is responsible for determining the PPE code for this material.

National Fire Protection Association

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Copyright 2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health, and reactivity hazards of chemicals. The user is referred to certain limited number of references with recommended classifications in NFPA 40 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the NFPA system to classify chemicals does so at their own risk.

References
Not available.

Notice to reader
To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.

Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

Date of issue/Date of revision: 5/12/2015
Date of previous issue: 5/12/2015
Version: 0.07 1317
EYE CONTACT: None
SKIN CONTACT: None
CHRONIC EFFECTS: None
OTHER EFFECTS OF OVEREXPOSURE: None

EXPOSURE INFORMATION:
ROUTE OF ENTRY: Inhalation
TARGET ORGANS: None
EFFECT: Asphyxiation (suffocation)
SYMPTOMS: Exposure to an oxygen-deficient atmosphere (<19.5%) may cause dizziness, incoherence, nausea, vomiting, cardiac arrhythmia, diminished mental alertness, loss of consciousness, and death.
MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None
CARCINOGENIC POTENTIAL: Hydrogen is not listed by NTP, OSHA, or IARC.

SECTION 4. FIRST AID

IMHALATION: Persons suffering from lack of oxygen should be removed to fresh air. If victim is not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.
SKIN CONTACT: None
EYE CONTACT: None
INGESTION: None
NOTES TO PHYSICIAN: None

SECTION 5. FIRE AND EXPLOSION

FLASH POINT: None
AUTOIGNITION: None
FLAMMABLE LIMITS: None

EXTINGUISHING MEDIA: CO2, dry chemical, water spray or fog for surrounding areas. Do not extinguish until hydrogen source is shut off.

HAZARDOUS COMBUSTION PRODUCTS: None

SPECIAL FIRE FIGHTING INSTRUCTIONS: Evacuate all personnel from danger area. Immediately cool equipment with water spray from maximum distance, taking care not to extinguish flames. If flames are accidentally extinguished, explosive re-ignition may occur. Stop flow of gas if possible while continuing cooling water spray.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Some with a pale blue, very irritant flame. Hydrogen is easily ignited with low-ignition energy, including static electricity. Hydrogen is lighter than air and can accumulate in the upper sections of enclosed spaces. Pressure in a container can build up due to heat, and it may rupture if pressure relief devices fail to function.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Evacuate immediate area. Eliminate any possible sources of ignition, and provide maximum explosion-proof ventilation. Shut off source of hydrogen, if possible, flushing from cylinder, or valve, call the Air Products emergency phone number. The presence of a hydrogen flame can be detected by approaching cautiously with an extinguished straw to smell the flame. Use a flame detecting device to detect the presence of hydrogen.

SECTION 9. MATERIAL SAFETY DATA SHEET

PRODUCT NAME: Hydrogen, compressed
CHEMICAL NAME: Hydrogen
FORMULA: H2
SYNONYMS: None
MANUFACTURER: Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18105-1587

PRODUCT INFORMATION:
MSDS NUMBER: 1009
REVISION: 4
REVISION DATE: June 1994

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS
Hydrogen is sold as pure product >99%
CAS NUMBER: 1333-74-0
EXPOSURE LIMITS:
OSHA: None
ACGIH: Simple asphyxiant

SECTION 3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW
Hydrogen is a flammable, colorless, odorless, compressed gas packaged in cylinders at high pressure. It poses an immediate fire and explosive hazard when concentrations exceed 4%. It is much lighter than air and turns with an invisible flame. High concentrations that will cause suffocation are within the flammable range and must not be entered.

EMERGENCY TELEPHONE NUMBERS
(908) 525-6378 Continental U.S., Canada, and Puerto Rico
(914) 481-7215 other locations

POSSIBLE HEALTH EFFECTS INFORMATION:

INHALATION: Asphyxiant. It should be noted that absence of symptoms is not unusual. The lower flammability limit of hydrogen in air would be exceeded possibly causing both an oxygen-deficient and explosive atmosphere. Exposure to noxious concentrations may cause dizziness, headaches, nausea, and unconsciousness. Exposure to atmospheres containing 8-10% or less oxygen will quickly bring about unconsciousness without warning leaving individuals unable to protect themselves. Lack of sufficient oxygen may cause serious injury or death.
SECTION 10. REACTIVITY/STABILITY

CHEMICAL STABILITY: Stable.

CONDITIONS TO AVOID: None.

INCOMPATIBILITY (Materials to Avoid): Oxidizing agents. Some steels are susceptible to hydrogen embrittlement at high pressures and temperatures.

REACTIVITY:
A) HAZARDOUS DECOMPOSITION PRODUCTS: None.
B) HAZARDOUS POLYMERIZATION: Will not occur.

SECTION 11. TOXICOLOGICAL INFORMATION

Hydrogen is a simple explosive.

SECTION 12. ECOLOGICAL INFORMATION

No adverse ecological effects are expected. Hydrogen does not contain any Class I or Class II ozone depleting chemicals (Subpart F of 40 CFR Part 82). Hydrogen is not listed as a marine pollutant by DOT (49 CFR Part 171).

SECTION 13. DISPOSAL

WASTE DISPOSAL METHOD: Do not attempt to dispose of residual or unabsorbed product in the cylinder. Return to supplier for safe disposal.

Residual product within process system may be vented at a controlled rate, to the atmosphere through a vent stack that discharges to an elevated point. This stack should be in an isolated area away from ignition sources.

SECTION 14. TRANSPORTATION

DOT NO.: 2191
HAZARD CLASS: Flammable gas
IDENTIFICATION NUMBER: UN 046
PRODUCT RG: None

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS

EPA - ENVIRONMENTAL PROTECTION AGENCY

SECTION 7. HANDLING AND STORAGE

STORAGE: Specific requirements are listed in NFPA 50A. Cylinder storage locations should be well-protected, well-ventilated, dry, and separated from combustible materials. Cylinders should never be allowed to reach a temperature exceeding 125°F (52°C). Cylinders of hydrogen should be separated from oxygen cylinders or other oxidizers by a minimum distance of 10 ft, or by a barrier of non-combustible material at least 3 ft high having a fire resistance rating of at least 1 hour.

Cylinders should be stored upright with valve protection caps in place and firmly secured to prevent falling or being knocked over. Protect cylinders from physical damage; do not drag, roll, slide or drop. Use a suitable hand truck for cylinder movement. Post "No Smoking or Open Flamed" signs in the storage areas. There should be no source of ignition. All electrical equipment should be explosion proof in the storage and use areas. Storage areas must meet national electric codes for class I hazardous areas.

HANDLING: Do not "open" hydrogen cylinder valve before connecting it, since self-ignition may occur. Hydrogen is the lightest gas known and may collect in the top of buildings with open ventilation. It may leak out of a system which is gas tight for air or other gases. Leak check system with leak detection solution, never with flame. If user experiences difficulty operating cylinder valve, discontinue use and contact supplier. Use only approved CSA connections. DO NOT USE ADAPTERS. Never insert an object (e.g., wrench, screwdriver, pry bar, etc.) into valve cap openings. Doing so may damage valve, causing a leak to occur. Use an adjustable wrench to remove or install cap. Never strike an arc on a compressed gas cylinder or make a cylinder a part of an electrical circuit.

SPECIAL PRECAUTIONS: Use piping and equipment adequately sized to withstand pressures to be encountered. Use a check valve or other protective apparatus in any line or piping from the cylinder to prevent reverse flow.

SECTION 8. PERSONAL PROTECTION/EXPOSURE CONTROLS

ENGINEERING CONTROLS: Provide natural or explosion-proof ventilation adequate to ensure hydrogen does not reach its lower explosive limit of 4%.

RESPRATORY PROTECTION:
General Use: None.
Emergencies: Use supplied-air respirators in oxygen-deficient atmospheres. Before entering an area you must check for flammable or oxygen-deficient atmospheres.

PROTECTIVE GLOVES: Work gloves are recommended when handling cylinders.

EYE PROTECTION: Safety glasses are recommended when handling cylinders.

OTHER PROTECTIVE EQUIPMENT: Safety shoes are recommended when handling cylinders.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE AND STATE: Colorless gas at normal temperature and pressure.

ODOR: Odorless.

MOLECULAR WEIGHT: 2.016
BOLING POINT (i atm): -243.0°F (-159.4°C)
SPECIFIC GRAVITY (air = 1): 0.0699
FREEZING POINT/BEDDING POINT: -334.5°F (-212.5°C)
VAPOR PRESSURE (at 76°F): Not applicable
GAS DENSITY (air = 1): 0.0626 lb/ft³ (0.00342 kg/m³)
SOLUBILITY IN WATER (at 68°F): 0.0092 lb/gal (0.0199/100g)
SPECIFIC VOLUME (at 70°F, 1 atm, 1 ft³): 192 ft³/lb (11.99/l)

SECTION 10. REACTIVITY/STABILITY

CHEMICAL STABILITY: Stable.

CONDITIONS TO AVOID: None.

INCOMPATIBILITY (Materials to Avoid): Oxidizing agents. Some steels are susceptible to hydrogen embrittlement at high pressures and temperatures.

REACTIVITY:
A) HAZARDOUS DECOMPOSITION PRODUCTS: None.
B) HAZARDOUS POLYMERIZATION: Will not occur.

SECTION 11. TOXICOLOGICAL INFORMATION

Hydrogen is a simple explosive.

SECTION 12. ECOLOGICAL INFORMATION

No adverse ecological effects are expected. Hydrogen does not contain any Class I or Class II ozone depleting chemicals (Subpart F of 40 CFR Part 82). Hydrogen is not listed as a marine pollutant by DOT (49 CFR Part 171).

SECTION 13. DISPOSAL

WASTE DISPOSAL METHOD: Do not attempt to dispose of residual or unabsorbed product in the cylinder. Return to supplier for safe disposal.

Residual product within process system may be vented at a controlled rate, to the atmosphere through a vent stack that discharges to an elevated point. This stack should be in an isolated area away from ignition sources.

SECTION 14. TRANSPORTATION

DOT NO.: 2191
HAZARD CLASS: Flammable gas
IDENTIFICATION NUMBER: UN 046
PRODUCT RG: None

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS

EPA - ENVIRONMENTAL PROTECTION AGENCY

Reportable Quantity (RQ): None
THE DOW CHEMICAL COMPANY
MATERIAL SAFETY DATA SHEET

Product Name: MONETHANOLAMINE
MSDS No: 1502
Effective Date: 06/17/2003

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

1.1 IDENTIFICATION

Product Name: MONETHANOLAMINE

1.2 COMPANY IDENTIFICATION

The Dow Chemical Company
Midland, MI 48674

1.3 EMERGENCY TELEPHONE NUMBER

24-HOUR EMERGENCY TELEPHONE NUMBER: (889)636-4400.
Customer Information Number: 1-800-256-2406.

SARA: Superfund Amendment and Reauthorization Act

SECTION 30234: Requires emergency planning on threshold planning quantities (TPQ) and release reporting based on reportable quantities (RQ) of EPA's extremely hazardous substances (40 CFR Part 355).

Emergency Hazardous Substance: None

Threshold Planning Quantity (TPQ): None

SECTION 311/312: Requires submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification of EPA defined hazard classes (40 CFR Part 370). The hazard classes for this product are:

IMMEDIATE: No
PRESSURE: Yes
DELAYED: No
REACTION: No
FLAMMABLE: Yes

SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR Part 372.

Hydrogen does not require reporting under Section 313

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:


Hydrogen is not listed as a regulated substance. However, any process that involves a flammable gas on site in one location, in quantities of 10,000 pounds (4,550 kg) or greater, is covered under this regulation.

TSCA: Toxic Substance Control Act. Hydrogen is listed on the TSCA inventory.

OTHER INFORMATION:

NFPA RATINGS:

HEALTH: = 0
FLAMMABILITY: = 4
REACTIVITY: = 0
SPECIAL: = SA (OSHA recommends this to designate simple asphyxiant)

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MATERIAL SAFETY DATA SHEET

Product Name: MONOETHANOLAMINE

Material Safety Data Sheet

246

Eye Contact  Liquids cause severe irritation, experienced as discomfort or pain, excess tearing and tear production, marked excess redness and swelling of the conjunctiva, and chemical burns of the cornea.

Skin Contact  Causes local discomfort or pain, severe excess redness and swelling, tissue destruction, fissures, ulceration, and possibly bleeding into the injured area.

Skin Absorption  Toxic. Prolonged or widespread contact may result in the absorption of potentially harmful amounts of material.

Swallowing  Aspiration into the lungs may occur during ingestion or vomiting, resulting in lung injury. Causes severe irritation or chemical burns of the mouth, throat, esophagus, and stomach, with pain or discomfort in the mouth, throat, chest, and abdomen, nausea, vomiting, diarrhea, dizziness, drowsiness, thirst, faintness, weakness, circulatory collapse, and coma.

Chronic  Prolonged or Repeated Exposure

Effects of Repeated Overexposure  Repeated overexposure may cause damage to kidney and liver.

Other Effects of Overexposure  None currently known.

Medical Conditions Aggravated by Exposure

Skin contact may aggravate an existing dermatitis. Inhalation of material may aggravate asthma and inflammatory or fibrotic pulmonary disease.

See Section 11 for toxicological information and additional information about potential health effects.

3.3 POTENTIAL ENVIRONMENTAL EFFECTS

See Section 12 for ecological information.

4. FIRST AID PROCEDURES

4.1 INHALATION

Remove to fresh air. Give artificial respiration if not breathing. If breathing is difficult, oxygen may be given by qualified personnel. Obtain medical attention.

4.2 EYE CONTACT

Immediately flush eyes with water and continue washing for at least 15 minutes. DO NOT remove contact lenses, if worn. Obtain medical attention without delay, preferably from an ophthalmologist.

5. FIRE FIGHTING MEASURES

5.1 FIRE FIGHTING

Firefighters should wear protective clothing and equipment. Use dry chemical, carbon dioxide, or class B foam. Cannot be controlled by water.

2. COMPOSITION INFORMATION

Component  CAS #  Amount (% WW)

MONOETHANOLAMINE  141-43-5  >= 59.5 %

3. HAZARDS IDENTIFICATION

3.1 EMERGENCY OVERVIEW

Appearance  Colorless

Physical State  Liquid

Odor  Ammoniacal

Hazards of product

CAUSES EYE AND SKIN BURNS.
HARMFUL IF INHALED OR ABSORBED THROUGH SKIN.
HARMFUL IF SWALLOWED.
KEEP AWAY FROM EYE OR CONTACT WITH SKIN.
ASPIRATION MAY CAUSE LUNG DAMAGE.
REPEATED EXPOSURE MAY CAUSE LIVER AND KIDNEY DAMAGE.

3.2 POTENTIAL HEALTH EFFECTS

Effects of Single Acute Overexposure

Inhalation  May cause irritation of the respiratory tract, experienced as nasal discomfort and discharge, coughing, and possibly accompanied by chest pain. Prolonged overexposure may cause injury to the respiratory tract.
MATERIAL SAFETY DATA SHEET

Product Name: MONOETHANOLAMINE  
MSDS#: 1502  
Effective Date: 09/17/2003

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5.6 HAZARDOUS COMBUSTION PRODUCTS
Burning can produce the following products: Oxides of carbon and nitrogen. Carbon monoxide is highly toxic if inhaled; carbon dioxide in sufficient concentrations can act as an asphyxiant. Acute overexposure to the products of combustion may result in irritation of the respiratory tract.

6. ACCIDENTAL RELEASE MEASURES
Steps to be Taken if Material is Released or Spilled:
Contain spilled material if possible. Collect in suitable and properly labeled containers. See Section 13, Disposal Considerations, for additional information.

Personal Precautions: Evacuate area. Refer to Section 7, Handling, for additional precautionary measures. Keep upwind of spill. Ventilate area of leak or spill. Only trained and properly protected personnel must be involved in cleanup operations.

Environmental Precautions: Prevent entering into soil, ditches, sewers, waterways and/or groundwater. See Section 12, Ecological Information.

7. HANDLING AND STORAGE

7.1 HANDLING
General Handling:
Do not get in eyes, on skin, or clothing. Avoid breathing vapor. Do not swallow.
Wash thoroughly after handling. Keep container closed.
Use with adequate ventilation. Do not use sodium nitrite or other nitrosating agents in formulations containing this product. Suspected cancer-causing nitrosamines could be formed.
See Section 8, EXPOSURE CONTROLS AND PERSONAL PROTECTION.

Ventilation:
Provide general and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

7.2 STORAGE
STABILITY - Monochloroamine and iron form a complex molecule, trichloroamine-iron. This material can spontaneously decompose at temperatures between 130° and 180°C, and has

MATERIAL SAFETY DATA SHEET

Product Name: MONOETHANOLAMINE  
MSDS#: 1502  
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4.3 SKIN CONTACT
Immediately remove contaminated clothing and shoes. Wash skin with soap and water. Obtain medical attention. Wash clothing before reuse. Discard contaminated leather articles such as shoes and belt.

4.4 SWALLOWING
If patient is fully conscious, give two glasses of milk or water at once. DO NOT INDUCE VOMITING. Obtain medical attention without delay.

4.5 NOTES TO PHYSICIAN
There is no specific antidote. Treatment of overexposure should be directed at the control of symptoms and the clinical condition of the patient. The hazards of this material are due mainly to its severely irritant properties on skin and mucous membranes.
Due to the irritant nature of the material, the stomach should be evacuated carefully in cases of poisoning by swallowing.

5. FIRE FIGHTING MEASURES

5.1 FLAMMABLE PROPERTIES - REFER TO SECTION 9, PHYSICAL AND CHEMICAL PROPERTIES

5.2 EXTINGUISHING MEDIA
Extinguish fires with water spray or apply alcohol-type or all-purpose-type foam by manufacturer's recommended techniques for large fires. Use carbon dioxide or dry chemical media for small fires.

5.3 FIRE FIGHTING PROCEDURES
Do not direct a solid stream of water or foam into burning molten material; this may cause spattering and spread the fire.

5.4 SPECIAL PROTECTIVE EQUIPMENT FOR FIREFIGHTERS
Use self-contained breathing apparatus, eye protection, and protective clothing.

5.5 UNUSUAL FIRE AND EXPLOSION HAZARDS
During fire, oxides of nitrogen may be evolved. See Section 8.3, - Engineering Controls.
MATERIAL SAFETY DATA SHEET

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical State: Liquid

Appearance: Colorless

Odor: Ammonial

Flash Point - Closed Cup: 96 °C 205 °F Pensky-Marten Closed Cup ASTM D 93

Flash Point - Open Cup: 104 °C 220 °F Cleveland Open Cup ASTM D 92

Flammability Limits In Air:

| Lower | No test data available |
| Upper | No test data available |

Autoignition Temperature: No test data available

Vapor Pressure: 0.2 mmHg 20 °C

Boiling Point (760 mmHg): 170 °C 338 °F

Vapor Density (air = 1): 2.1

Specific Gravity (H2O = 1): 1.017 20 °C / 20 °C

Freezing Point: 11 °C 51.8 °F

Melting Point: Not applicable

Solubility in Water (by weight): 100 % 20 °C

pH: No test data available.

Molecular Weight: 61 g/mol

Octanol/Water Partition Coefficient - Measured: -1.31

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MATERIAL SAFETY DATA SHEET

8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

8.1 EXPOSURE LIMITS

Component | Exposure Limits | Skin | Form |
--- | --- | --- | --- |
Monoethanolamine | 3 ppm TWA OSHA | 3 ppm TWA OSHA | 6 ppm STEL OSHA | 6 mg/m3 TWA ACGIH |

In the Exposure Limits Chart above, if there is no specific qualifier (i.e., Aroso) listed in the Form Column for a particular limit, the listed limit includes all airborne forms of the substance that can be inhaled.

An "Yes" in the Skin Column indicates a potential significant contribution to overall exposure by the cutaneous (skin) route, including mucous membranes and the eyes, either by contact with vapors or by direct skin contact with the substance. A "Blank" in the Skin Column indicates that exposure by the cutaneous (skin) route is not a potential significant contributor to overall exposure.

8.2 PERSONAL PROTECTION

Respiratory Protection: Atmospheric levels should be maintained below the exposure guidelines. When airborne exposure guidelines and/or comfort levels may be exceeded, use an approved air-purifying respirator.

For emergency response or for situations where the atmospheric level is unknown, use an approved positive-pressure self-contained breathing apparatus or positive-pressure airline with auxiliary self-contained air supply.

Ventilation: Provide general and/or local exhaust ventilation to control airborne levels below the exposure guidelines.

Eye Protection: Monogoggles.
Peroral
Combined effects for males and females:

Major Signs: sluggishness, lacrimation, prostration, kyphosis, unsteady gait, emaciation, pallor, red or brown discharge on pinnae, periorbital, and serous exudates.

Gross Pathology: lungs, kidneys, stomachs, and intestines discolored; liver and stomach adhesions; stomach gas; or liquid filled.

Percutaneous

Rabbit, male: LD50 = 2.46 (1.76 - 3.39) mL/kg; slope = 5.60; 24 h occluded.
Time to Death: 1 to 13 days.

Percutaneous

Rabbit, female: LD50 = 2.83 (1.61 - 4.98) mL/kg; slope = 3.89; 24 h occluded.
Time to Death: 1 to 13 days.

Percutaneous
Combined effects for males and females:

Major Signs: sluggishness, subtle breathing in one, abdominal distention, prostration in one, emaciation, inactivity.

Gross Pathology: numerous organs discolored, hemorrhaged intestines, stomachs and intestines filled with liquid or gas-filled.

Inhalation
Substantially saturated vapor studies, 6-hour exposure, static-generation method: Rat, male and female
Mortality: 0/5

Evaporation Rate (Butyl Acetate = 1): 0.02
Percent Volatiles: 100 W%
MATERIAL SAFETY DATA SHEET

GENETIC TOXICOLGY

In Vitro
This material was not genotoxic in various mutagenicity and clastogenicity tests.

In Vivo
This material was not genotoxic in various mutagenicity and clastogenicity tests.

PHARMACOKINETICS AND METABOLISM

In Vivo
As reported in the literature, the fate of ethylamine-1, 2-C14 in the intact rat, tissue slices, and homogenates resulted in 54% of the dose in the liver, spleen, kidneys, heart, brain, and diaphragm and 11.5% as CO2, 6 hr after intraperitoneal administration. The liver was the most active tissue followed by the heart and brain. MEA is incorporated into the liver phosphatidylcholines via phosphatidylethanolamine and CDP-ethanolamine (cytidine-5-diphosphoethanolamine).

SIGNIFICANT DATA WITH POSSIBLE RELEVANCE TO HUMANS

Inhalation studies of monoethanolamine (MEA) in laboratory animals produced effects which suggest possible injury to the nervous system. Laboratory study suggests that rats given high doses of MEA by gavage produced increased embryotoxicity, growth retardation and some malformations (hydroxyproline/hydroxylysine). Due to the high doses used and other technical deficiencies, the validity of this study is somewhat questionable. There is evidence that no embryotoxicity or teratogenicity was produced in rats or rabbits when MEA was administered by skin contact, a more relevant route of potential human exposure.

12. ECOLOGICAL INFORMATION

12.1 ENVIRONMENTAL FATE

The following information is applicable to monoethanolamine.

BOD (% Oxygen consumption)

<table>
<thead>
<tr>
<th>Day 5</th>
<th>Day 10</th>
<th>Day 15</th>
<th>Day 20</th>
<th>Day 28/30</th>
</tr>
</thead>
<tbody>
<tr>
<td>92 %</td>
<td>75 %</td>
<td>50 %</td>
<td>100 %</td>
<td></td>
</tr>
</tbody>
</table>

BOD (% Oxygen consumption)

<table>
<thead>
<tr>
<th>Day 5</th>
<th>Day 10</th>
<th>Day 15</th>
<th>Day 20</th>
<th>Day 28/30</th>
</tr>
</thead>
<tbody>
<tr>
<td>52 %</td>
<td>73 %</td>
<td>90 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MATERIAL SAFETY DATA SHEET

Gross Pathology: nothing remarkable.

IRRITATION

Skin: Rabbit: 4-hour occluded contact: 0.5 ml
Result: severe erythema, edema and necrosis with subsequent ulceration and scabbing, severe irritation persisted through 14 days.

Skin: Rabbit: 4-h occluded
Result: corrosive

Eye: Rabbit: 0.005 ml
Result: severe corneal injury with vasodilatation and corneal edema, severe iritis, severe conjunctival irritation with necrosis and hemorrhages, healed by 21 days.

REPEATED EXPOSURE

In an inhalation study with rats, guinea pigs, and dogs presented in the literature, doses varied up to 122 ppm over durations ranging from 3.5-13 hrs for rats, 3.5 hrs for guinea pigs, and 4-13 hrs for dogs. Major signs at high exposures included mortality, severe stress, breathing difficulties, and behavior changes. Histopathological changes were observed in lungs and nasal mucosa in guinea pigs and in lungs and kidneys in guinea pigs and dogs. At exposure levels above 30 ppm, epidermal ulceration was observed, with severe necrosis of the nasal mucosa and tracheal epithelium.

SENSITIZATION (ANIMAL AND HUMAN STUDIES)

A repeated insult patch test was carried out on human volunteers. No skin reaction was observed.

DEVELOPMENTAL TOXICITY

In a developmental study with rats reported in the literature, doses of up to 450 mg/kg were administered by gavage. Significant reductions in food consumption and body weight were observed in the 450 mg/kg group. The NOEL was 120 mg/kg/day for maternal toxicity and greater than 450 mg/kg/day for embryotoxicity and teratogenicity. No increases in malformation rate or growth retardation were observed in fetuses or pups, indicating that MEA was not embryotoxic or teratogenic in the rat following gavage exposure. In a subsequent study with rats, doses of up to 225 mg/kg were administered. Severe skin irritation or lesions and a significant decrease in body weight gain were observed at 225 mg/kg/day. The NOEL was 750 mg/kg/day for maternal toxicity and greater than 225 mg/kg/day for embryotoxicity and teratogenicity. A study with rabbits had similar results. The NOEL was 25 mg/kg/day for maternal toxicity and greater than 75 mg/kg/day for embryotoxicity and teratogenecity.
13.1 DISPOSAL

DO NOT DUMP INTO ANY SEWERS, ON THE GROUND, OR INTO ANY BODY OF WATER.
All disposal practices must be in compliance with all Federal, State/Provincial and local laws and regulations. Regulations may vary in different locations. Waste characterization and compliance with applicable laws are the responsibility solely of the waste generator. Dow has no control over the management practices or manufacturing processes of parties handling or using this material. The information presented here pertains only to the product as shipped in its intended condition as described in MSDS Section 2. Composition/Information on Ingredients. For unused & uncontaminated product, the preferred options include sending to a licensed, permitted incinerator or other thermal destruction device. As a service to its customers, Dow can provide names of information resources to help identify waste management companies and other facilities which recycle, reprocess or manage chemicals or plastics, and that manage used drums. Telephone Dow's Customer Information Group at 1-800-258-2436 or 1-888-832-1588 (U.S.); or 1-800-331-5401 (Canada) for further details.

14. TRANSPORT INFORMATION

14.1 U.S. DOT

NON-BULK
Proper Shipping Name: ETHANOLAMINE
Hazard Class: 2
ID Number: UN2491
Packing Group: PG III

BULK
Proper Shipping Name: ETHANOLAMINE
Hazard Class: 2
ID Number: UN2491
Packing Group: PG III

This information is not intended to convey all specific regulatory or operational requirements/information relating to this product. Additional transportation system information can be obtained through an authorized sales or customer service representative. It is the responsibility of the transporting organization to follow all applicable laws, regulations and rules relating to the transportation of the material.

15. REGULATORY INFORMATION

12.2 ECOTOXICITY

Toxicity to Micro-organisms
Bacterial inhibition: IC50
Result value: 780 mg/L

Toxicity to Micro-organisms
Sediment inhibition: IC50
Result value: > 2000 mg/L

Toxicity to Aquatic Invertebrates
Daphnia: 48 h: LC50
Result value: 22 mg/L

Toxicity to Aquatic Invertebrates
Daphnia: 48 h: LC50
Result value: 92 mg/L

Toxicity to Fish
Fathead Minnow: 96 h: LC50
Result value: 102 mg/L

Toxicity to Fish
Fathead Minnow: 96 h: LC50
Result value: 289 mg/L

12.3 FURTHER INFORMATION

THODCARB
Theoretical Oxygen Demand (THOD) - calculated: 1.31 mg/L

THODCTR
Theoretical Oxygen Demand (THOD) - calculated: 0.79 mg/L

Chemical Oxygen Demand (COD) - measured: 1.54 mg/L

Octanol/Water Partition Coefficient - Measured: -1.31

15. DISPOSAL CONSIDERATIONS
15.2 STATE/LOCAL

Pennsylvania (Worker and Community Right to Know Act): Pennsylvania Hazardous Substances List and/or Pennsylvania Environmental Hazardous Substances List

The following product components are listed in the Pennsylvania Hazardous Substance List and/or the Pennsylvania Environmental Substance List, and are present at levels which require reporting:

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS #</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoethanolamine</td>
<td>141-43-6</td>
<td>&lt; 100,000%</td>
</tr>
</tbody>
</table>

Pennsylvania (Worker and Community Right to Know Act): Pennsylvania Special Hazardous Substances List

To the best of our knowledge this product does not contain chemicals at levels which require reporting under this statute.

California Proposition 65 (Safe Drinking Water and Toxic Enforcement Act of 1986)

This product contains no listed substances known to the State of California to cause cancer, birth defects or other reproductive harm, at levels which would require a warning under the statute:

California SCAGMD Rule 443.1 (South Coast Air Quality Management District Rule 443.1, Labeling of Materials Containing Organic Solvents)

VOC: 0.2 mmHg @ 30 °C
1014 g/ft³ VOC
1016 g/ft³ less water and less exempted solvents

This section provides selected regulatory information on this product including its components. This is not intended to include all regulations. It is the responsibility of the user to know and comply with all applicable rules, regulations and laws relating to the product being used.

16. OTHER INFORMATION

15.1 FEDERAL/NATIONAL

OSHA Hazard Communication Standard

This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.

Superfund Amendments and Reauthorization Act of 1986 Title III (Emergency Planning and Community Right to Know Act) Section 313

To the best of our knowledge this product does not contain chemicals at levels which require reporting under this statute.

Superfund Amendments and Reauthorization Act of 1986 Title III (Emergency Planning and Community Right to Know Act) Sections 311 and 312

Delayed (Chronic) Health Hazard: No
Immediate (Acute) Health Hazard: Yes
Reactive Hazard: No
Sudden Release of Pressure Hazard: No

CEPA - Domestic Substances List (DSL)

All substances contained in this product are listed on the Canadian Domestic Substances List (DSL) or are not required to be listed.

Toxic Substances Control Act (TSCA)

All components of this product are on the TSCA Inventory or are exempt from TSCA Inventory requirements.
16.1 ADDITIONAL INFORMATION

ADDITIONAL INFORMATION: Additional product safety information on this product may be obtained by calling Dow's Customer Information Group at 1-800-258-2436 (U.S.) or 1-800-331-6451 (Canada).
Ask for the brochure:
Ethanolamines (Family Brochure)
Ethanolamines Storage and Handling (Brochure)

16.2 HAZARD RATING SYSTEM

NFPA ratings for this product are: H = 3, F = 1, R = 0

These ratings are part of a specific hazard communication program and should be disregarded where individuals are not trained in the use of this hazard rating system. You should be familiar with the hazard communication programs applicable to your workplace.

16.3 RECOMMENDED USES AND RESTRICTIONS

FOR INDUSTRY USE ONLY

16.4 REVISION

Version: 5.
Revision: 06/17/2003.
Most recent revision(s) are noted by the bold, double bars in left-hand margin throughout this document.

16.5 LEGEND

Bacterial/VA  Non Acclimated Bacteria
F  Fire
H  Health
HG  Industrial Hygiene Guideline
N/A  Not available
NFPA  National Fire Protection Association
Q  Oxidizer
R  Reactivity
TS  Trade secret
MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: Methane
FORMULA: CH4

CHEMICAL NAME: Methane, Saturated Aliphatic Hydrocarbon, Allene
SYNONYM: Methyl Hydride; Methane Gas; Fire Camp

MANUFACTURER: Air Products and Chemicals, Inc.
7251 Hamilton Boulevard
Allentown, PA 18195 - 1101

PRODUCT INFORMATION: 800-752-1597

MSDS NUMBER: 1070
REVISION: 0
REVIEW DATE: July 1998
REVISED DATE: July 1998

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

Methane is packaged as pure product (>99%).

CAS NUMBER: 74-98-5

EXPOSURE LIMITS:
OSHA: None established
ACGIH: Simple Asphyxiant
NIOSH: None established

SECTION 3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

Methane is a flammable, colorless, odorless, compressed gas packaged in cylinders under high pressure. It poses an immediate fire and explosion hazard when mixed with air at concentrations exceeding 5%. High concentrations that can cause rapid suffocation are within the flammable range and should not be entered.

EMERGENCY TELEPHONE NUMBERS
800 - 523 - 0714 in Continental U.S., Canada and Puerto Rico
610 - 481 - 7711 outside U.S.

ACUTE POTENTIAL HEALTH EFFECTS:

ROUTES OF EXPOSURE:

INHALATION: Methane is non-toxic. It can, however, reduce the amount of oxygen in the air necessary to support life. Exposure to oxygen-deficient atmospheres (less than 19.5%) may produce dizziness, nausea, vomiting, loss of consciousness, and death. At very low oxygen levels, death may occur without warning. It should be noted that before suffocation could occur, the lowest flammable limit for Methane in air will be reached, resulting in an oxygen deficient and an explosive atmosphere.

SKIN CONTACT: No harmful affect.

POSSIBLE HEALTH EFFECTS OF REPEATED EXPOSURE:

ROUTE OF ENTRY: None
SYMPTOMS: None

SECTION 4. FIRST AID MEASURES

EYE CONTACT: No treatment necessary.
INTESTINAL INGESTION: Not applicable
INHALATION: Provide fresh air. If not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.

SKIN CONTACT: No treatment necessary.
NOTES TO PHYSICIAN: Treatment of overexposure should be directed at the control of symptoms and the clinical condition.

SECTION 5. FIRE FIGHTING MEASURES

FLASH POINT: >506 °F (263 °C)
FLAMMABILITY RANGE: 5.0% - 15%

EXTINGUISHING MEDIA: Dry chemical, carbon dioxide, or water.

SPECIAL FIRE FIGHTING INSTRUCTIONS: Evacuate personnel from area. If possible, without risk, shut off source of methane, then fight fire according to type of materials burning. Extinguish fire only if gas flow can be stopped. This will avoid possible accumulation and reignition of a flammable gas mixture. Keep adjacent cylinders cool by sprinkling with large amounts of water until the fire has been put out. Self-contained breathing apparatus (SCBA) may be required.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a cylinder can build up due to heat and it may rupture if pressure relief devices fail to function.

HAZARDOUS COMBUSTION PRODUCTS: Carbon monoxide

SECTION 6. ACCIDENTAL RELEASE MEASURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED: Evacuate immediate area. Eliminate any possible sources of ignition. Provide adequate explosion-proof ventilation. Use a flammable gas water mist (water-glycol) extinguisher for Methane to control a fire. Never enter an area where Methane concentration is greater than 1.5% (which is 20% of the lower flammability limit). If personnel are exposed to any concentration of flammable gases, fire and explosion danger exists. Use portable gas detectors containing a LEL sensor and a 5% O2 sensor. Shut off source of gas if possible. Isolate any leaking cylinder. If leak is in container, pressure relief device or its valve, contact your supplier. If the leak is in the user’s system, close the cylinder valve, safety vent the pressure, and purge with an inert gas before attempting repairs.

SECTION 7. STORAGE AND HANDLING

STORAGE: Store cylinders in a well-ventilated, secure area, protected from weather. Cylinders should be stored upright with valve outlet seals and valve protection caps in place. There should be no sources of ignition. All electrical equipment should be explosion-proof in the storage areas. Flammable storage areas must be separated from oxygen and other oxidizers by a minimum distance of 20 ft. or by a barrier of non-combustible material at least 5 ft. high having a fire resistance rating of at least 1 hour. Full & empty cylinders shall be stored in a manner to prevent damage from rolling or tipping over. Full & empty cylinders shall be segregated. Full & empty cylinders should be segregated. Use a flash- flame interruption system to prevent flash containers from being stored for long periods of time.

HANDLING: Do not drag, roll, slide or drop cylinder. Use a suitable hand truck designed for cylinder movement. Never attempt to lift a cylinder by its cap. Secure cylinders at all times while in use. Use a pressure reducing regulator to safely discharge gas from cylinder. Use a check valve to prevent reverse flow.
SECTION 12. ECOLOGICAL INFORMATION

AQUATIC TOXICITY: Not determined
MOBILITY: Not determined
PERISTRICE AND BIODEGRADABILITY: Not determined
POTENTIAL TO BIOACCUMULATE: Not determined

REMARKS: This product does not contain any Class I or Class II ozone depleting chemical.

SECTION 13. DISPOSAL CONSIDERATIONS

UNUSED PRODUCT/EMPTY CONTAINER: Return container and unused product to supplier. Do not attempt to dispose of residual or unused quantities.

DISPOSAL INFORMATION: Residual product in the system may be burned if a suitable burning unit (i.e., incinerator) is available on site. This shall be done in accordance with federal, state, and local regulations. Vessels containing this material may be classified by EPA as hazardous waste by characteristic (i.e., ignitability, corrosion, leachability, reactivity). Waste streams must be characterized by the user to meet federal, state, and local requirements.

SECTION 14. TRANSPORT INFORMATION

DOT SHIPPING NAME: Methane, compressed
HAZARD CLASS: 2.1
IDENTIFICATION NUMBER: UN1971
SHIPPING LABEL: Flammable gas
PLACARD (if required): Flammable gas

SPECIAL SHIPPIING INFORMATION: Cylinders should be transported in a secured upright position in a well-ventilated area. Never transport in the passenger compartment of a vehicle. Ensure cylinder valve is properly closed, valve outlet has been reinstalled, and valve protective cap is secured before shipping cylinder.

CAUTION: Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner’s written consent is a violation of Federal law (49 CFR 173.301).

NORTH AMERICAN EMERGENCY RESPONSE GUIDELINES NUMBER (NAERG #): 115

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS

EPA - ENVIRONMENTAL PROTECTION AGENCY


MOLECULAR WEIGHT: 16.04
BOILING POINT (1 atm): -252.7°F (-161.5°C)
SPECIFIC GRAVITY (Air = 1): 0.584
VAPOR PRESSURE (M/100°F @ 40°C): 298.5°F (-182.5°C)
GAS DENSITY (NHe): 29.7 kg/m³ (1001 lb/ft³)
SOLUBILITY IN WATER (saturated): 3.3 mol/g (1001 lb/ft³)

SECTION 19. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable

CONDITIONS TO AVOID: Do not expose to temperatures in excess of 125°F (52°C). Incompatibility (Materials to Avoid): Oxygen, Halogens and Oxidizers

REACTIVITY: None

SECTION 11. TOXICOLOGICAL INFORMATION

LC50 (Inhalation): Not applicable. Slightly asphyxiating.
LD50 (Oral): Not applicable
LD50 (Dermal): Not applicable

SKIN CORROSIVITY: Methane is not corrosive to the skin.

ADDITIONAL NOTES: None
MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: Nitrogen, compressed
CHEMICAL NAME: Nitrogen
FORMULA: N₂
SYNONYMS: Nitrogen gas, Oxenous Nitrogen, GAN
MANUFACTURER: Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18105 - 1001

PRODUCT INFORMATION:
MSDS NUMBER: 1011
REVISION DATE: March 1994
REVIEW DATE: August 1997

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

Nitrogen is sold as a compressed gas.
CAS NUMBER: 7727-37-9
EXPOSURE LIMITS: OSHA: Not established
AGHS: Simple asphyxiant
NIOSH: Not established

SECTION 3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
Nitrogen is a non-toxic, odorless, colorless, nonflammable compressed gas stored in cylinders at high pressure. It can cause rapid suffocation when concentrations are sufficient to reduce oxygen levels below 19.5%. Self Contained Breathing Apparatus (SCBA) may be required.

EMERGENCY TELEPHONE NUMBERS
800-529-0374 Continental U.S., Canada and Puerto Rico
610-481-7111 other locations

POTENTIAL HEALTH EFFECTS INFORMATION:
INHALATION: Simple asphyxiant. Nitrogen is non-toxic, but may cause suffocation by displacing the oxygen in air. Lack of sufficient oxygen can cause serious injury or death.
EYE CONTACT: No adverse effect.
SKIN CONTACT: No adverse effect.

EXPOSURE INFORMATION:
ROUTE OF ENTRY: Inhalation
TARGET ORGANS: None
damage valve causing a leak to occur. Use a special cap wrench or adjustable strap wrench to remove overtight or rusted caps.

Nitrogen is compatible with all common materials of construction. Pressure requirements should be considered when selecting materials and designing systems.

SPECIAL REQUIREMENTS: Always store and handle compressed gases in accordance with Compressed Gas Association, Inc. (pH. 703-412-0000) pamphlet CGA P-1. Safe Handling of Compressed Gases in Containers. Local regulations may require specific equipment for storage or use.

CAUTION: Users of nitrogen must be aware of the hazards caused by the accumulation of high concentrations, especially in confined spaces. Compliance with OSHA regulations, especially 29CFR1910:146 (confined space entry), is essential.

SECTION 3. PERSONAL PROTECTION / EXPOSURE CONTROL

ENGINEERING CONTROLS: Provide good ventilation and local exhaust to prevent accumulation of high concentrations of gas. Oxygen levels in work area should be monitored to ensure they do not fall below 19.5%.

RESPIRATORY PROTECTION: GENERAL USE: None required.

EMERGENCY: Use SCBA or positive pressure air line with mask or escape pack in areas where oxygen concentration is less than 19.5%. An air purifying respirator will not provide protection.

OTHER PROTECTIVE EQUIPMENT: Safety glasses. Safety shoes and leather work gloves are recommended when handling cylinders.

SECTION 4. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE: Colorless gas

ODOR: Odorless

MOLECULAR WEIGHT: 28.01

BOILING POINT (1 Atmosphere): -320.4 °F (-195.8 °C)

SPECIFIC GRAVITY (Air = 1): 0.867

SPECIFIC HEAT (at 70 °F, 21.1 °C and 1 atm): 1.301 Btu/lb °F (0.0677 kJ/kg °C)

FREEZING POINT (Melting Point): -334.5 °F (-210.9 °C)

VAPOR PRESSURE: None applicable at 70 °F

GAS DENSITY (at 70 °F, 21.1 °C and 1 atm): 0.72 lb/ft³ (1.153 kg/m³)

SOLUBILITY IN WATER (molar): at 32°F (0 °C): 0.033

SECTION 5. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable

CONDITIONS TO AVOID: None

INCOMPATIBILITY: None

HAZARDOUS DECOMPOSITION PRODUCTS: None

HAZARDOUS POLYMERIZATION: Will not occur.

SECTION 6. TOXICOLOGICAL INFORMATION

Nitrogen is a simple asphyxiant.

EFFECT: Asphyxiation (suffocation)

SYMPTOMS: Exposure to an oxygen deficient atmosphere (<19.5%) may cause dizziness,itations, nausea, vomiting, excessive salivation, diminished mental alertness, rapid loss of consciousness and death. Exposure to atmospheres containing 8-10% less oxygen will bring about unconsciousness without warning and so quickly that the individuals cannot free themselves.

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None

CARCINOGENIC POTENTIAL: Nitrogen is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA.

SECTION 7. FIRE AND EXPLOSION

FLASH POINT: Not applicable

AUTODESTRUCTION: Not applicable

FLAMMABLE LIMITS: Not applicable

EXTINGUISHING MEDIA: Nitrogen is nonflammable and does not support combustion. Use extinguishing media appropriate for the surrounding fire.

HAZARDOUS COMBUSTION PRODUCTS: None

SPECIAL FIRE FIGHTING INSTRUCTIONS: Nitrogen is a simple asphyxiant. If possible, remove nitrogen cylinders from fire area or cool with water. SCBA may be required by rescue workers.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Upon exposure to intense heat or flame, cylinder may vent rapidly and/or rupture violently. Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a container can build up due to heat and it may rupture if pressure relief devices should fail to function.

SECTION 8. ACCIDENTAL RELEASE MEASURES

Evacuate all personnel from affected area. Increase ventilation to release area and monitor oxygen level. Use appropriate protective equipment (SCBA). If leak is from container or its valve, call the Air Products emergency telephone number. If leak is in user's system close cylinder valve and vent pressure before attempting repairs.

SECTION 9. HANDLING AND STORAGE

STORAGE: Cylinders should be stored upright in a well-ventilated, secure area, protected from the weather. Storage area temperatures should not exceed 125 °F (52 °C) and area should be free of combustible materials. Storage should be away from heavily traveled areas and emergency exits. Avoid areas where salt or other corrosive materials are present. Valve protection caps and valve outlet seals should remain on cylinders not connected for use. Separate full from empty cylinders. Avoid excessive inventory and storage time. Use a first-in/first-out system. Keep good inventory records.

HANDLING: Do not drag, roll, or skid cylinder. Use a suitable handtruck designed for cylinder movement. Never attempt to lift a cylinder by its cap. Secure cylinders at all times while in use. Use a pressure reducing regulator or separate control valve to safely discharge gas from cylinder. Use a check valve to prevent reverse flow into cylinder. Do not overload cylinder to increase pressure or discharge rate. If user experiences any difficulty operating cylinder valve, discontinue use and contact supplier. Never invert an object (e.g., wrench, screwdriver, pipe or etc.) into valve cap openings. Doing so may
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**SECTION 12. ECOLOGICAL INFORMATION**

The atmosphere contains approximately 78% nitrogen. No adverse ecological effects are expected. Nitrogen does not contain any Class I or Class II ozone-depleting chemicals. Nitrogen is not listed as a marine pollutant by DOT (49 CFR 172).

**SECTION 13. DISPOSAL**

**UNUSED PRODUCT / EMPTY CONTAINER:** Return cylinder and unused product to supplier. Do not attempt to dispose of residual or unused quantities.

**DISPOSAL:** For emergency disposal, secure the cylinder and slowly discharge gas to the atmosphere in a well-ventilated area or outdoors.

**SECTION 14. TRANSPORT INFORMATION**

**DOT HAZARD CLASS:** 2.2

**DOT SHIPPING NAME:** Compressed Nitrogen

**IDENTIFICATION NUMBER:** UN1096

**REPORTABLE QUANTITY (RQ):** None

**SPECIAL SHIPPING INFORMATION:** Cylinders should be transported in a secure upright position in a well-ventilated truck. Never transport in passenger compartment of a vehicle. Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner’s written consent is a violation of federal law.

**SECTION 15. REGULATORY INFORMATION**

**U.S. FEDERAL REGULATIONS:**

**ENVIRONMENTAL PROTECTION AGENCY (EPA):**

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980

SARA TITLE III: Superfund Amendment and Reauthorization Act of 1986

SECTION 303/304: Requires emergency planning on threshold planning quantities (TPQ) and release reporting based on reportable quantities (RQ) of EPA’s extremely hazardous substances (40 CFR 355).

Nitrates is not listed as an extremely hazardous substance.

Threshold Planning Quantity (TPQ): None

**SECTION 311/312:** Requires submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification of EPA defined hazard classes. The hazard classes for this product are:

- **IMMEDIATE HEALTH:** No
- **PRESSURE:** Yes
- **DELAYED HEALTH:** No
- **REACTIONITY:** No
- **FIRE:** No

**SECTION 313:** Requires submission of annual reports of releases of toxic chemicals that appear in 40 CFR 372.

Nitrogen does not require reporting under Section 313.

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**SECTION 16. OTHER INFORMATION**

**NFPA RATINGS:**

- **HEALTH:** 0
- **FLAMMABILITY:** 0
- **REACTIONITY:** 0

**HMS RATINGS:**

- **HEALTH:** 0
- **FLAMMABILITY:** 0
- **REACTIONITY:** 0

**SPECIAL:** 5A

*Compressed Gas Association recommendation to designate simple asphyxiant.*

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**Documents with Review Dates August 1997 and Revision Date March 1994 are identical in content and either may be used.**
EXPOSURE INFORMATION:

ROUTE OF ENTRY: Inhalation

TARGET ORGANS: Eyes, central nervous system

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: Patients with chronic obstructive pulmonary disease may retain carbon dioxide abnormally. If oxygen is administered to them, raising the oxygen concentration in the blood depresses their breathing and raises their retained carbon dioxide to a dangerous level.

CARCINOGENIC POTENTIAL: Oxygen is not listed as a carcogen or potential carcogen by NTP, IARC, or OSHA Subpart Z.

SECTION 4. FIRST AID

INHALATION: Move victim to fresh air or if elevated pressures reduce oxygen pressures to one atmosphere. Call a physician. The physician should be advised that the victim has been exposed to a high concentration of oxygen. No treatment is required in the absence of symptoms or high pressure exposure.

EYE/SKIN CONTACT: Not applicable

NOTES TO PHYSICIAN: Animal studies suggest that the administration of certain drugs, including methemoglobin-forming drugs and chlorpromazine, increase the susceptibility to toxicity from oxygen at high pressures. Animal studies also indicate that vitamin E deficiency may increase susceptibility to oxygen toxicity.

Airway obstruction during high oxygen tension may cause alveolar collapse following absorption of the oxygen. Similarly, occlusion of the Eustachian tubes may cause retraction of the eardrum and obstruction of the paranasal sinuses may produce "vacuum-type" headache.

All individuals exposed for long periods to oxygen at high pressure who exhibit overt oxygen toxicity should have ophthalmologic examinations.

SECTION 5. FIRE AND EXPLOSION

FLASH POINT: Not applicable

AUTOIGNITION: Not applicable

FLAMMABLE LIMITS: Not applicable

EXTINGUISHING MEDIA: Oxygen is not flammable, but will support combustion. Use extinguishing media appropriate for surrounding fire.

HAZARDOUS COMBUSTION PRODUCTS: None

SPECIAL FIRE FIGHTING INSTRUCTIONS: Evacuate all personnel from the danger area. If possible, shut off flow of oxygen which is supplying the fire. Immediately cool container with water spray from maximum distance. When cool, move cylinders from fire area. If possible without risk, self-contained breathing apparatus may be required for rescue workers.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Oxygen vigorously accelerates combustion. Some materials which are noncombustible in air, will burn in the presence of pure oxygen. Combustible materials exposed to pure oxygen may react very rapidly with the oxygen, and may cause fire or explosion. Heat generated by the reaction may ignite flammable or combustible materials. Extinguish fire in container can build up due to heat and it may rupture if pressure relief devices fail to function. Upon exposure to intense heat or flame cylinder will vent rapidly and/or rupture violently. Most cylinders are designed to vent contents when exposed to elevated temperatures. Pressure in a container can build up due to heat and it may rupture if pressure relief devices fail to function.

MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: Oxygen, Compressed

CHEMICAL NAME: Oxygen

FORMULA: O₂

SYNONYMS: Oxygen gas, Atmospheric Oxygen, GOX

MANUFACTURER: Air Products and Chemicals, Inc.

7201 Hamilton Boulevard
Allentown, PA 18195 – 1501

PRODUCT INFORMATION: 9-000-752-1597

MSDS NUMBER: 1012

REVISION: 5

REVISED DATE: January 1995

REVIEW DATE: August 1997

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

Oxygen is stored as a high-pressure gas (995%).

CAS NUMBER: 7782-44-7

EXPOSURE LIMITS:

OSHA: Not established

ACGIH: Not established

NIOSH: Not established

SECTION 3. HAZARD IDENTIFICATION

EMERGENCY OVERVIEW

Oxygen is an odourless, colourless, non-flammable gas stored in cylinders at high pressure. It is an oxidizing gas and vigorously accelerates combustion. Keep away from oils or grease. Remove personnel should be aware of the extreme fire hazards associated with oxygen-enriched (greater than 23%) atmospheres, and that self-contained breathing apparatus (SCBA) may be required.

EMERGENCY TELEPHONE NUMBERS

(800) 523-8334 Continental U.S., Canada and Puerto Rico

(816) 881-7711 other locations

POTENTIAL HEALTH EFFECTS INFORMATION:

INHALATION: Breathing 80% or more oxygen at atmospheric pressure for more than a few hours may cause nasal stuffiness, cough, sore throat, chest pain and breathing difficulty. Breathing oxygen at higher pressure increases the likelihood of adverse effects within a shorter time period. Breathing pure oxygen under pressure may cause lung damage and also central nervous system effects resulting in dizziness, poor coordination, tingling sensation, visual and hearing disturbances, muscular twitching, unconsciousness and convulsions. Breathing oxygen under pressure may cause prolongation of adaptation to darkness and reduced peripheral vision.

EYE/SKIN CONTACT: No adverse effect.
SECTION 6. ACCIDENTAL RELEASE MEASURES

Evacuate all personnel from affected area. Shut off source of oxygen if possible. Increase ventilation to release area. Personnel who have been exposed to high concentrations of oxygen should be hospitalized immediately. Consult local emergency service or environmental health and safety officials before releasing cylinder. Follow procedures outlined in the Air Products emergency telephone number. If leak is in user's system close cylinder valve and vent pressure before attempting repairs.

SECTION 7. STORAGE AND HANDLING

STORAGE: Cylinders should be stored upright in a well-ventilated, secure area, protected from the weather. Storage area temperatures should not exceed 125 °F (52 °C) and area should be free of combustible materials. Storage should be away from heavily traveled areas and emergency exits. Avoid areas where solid or other corrosive materials are present. Cylinders should be separated from flammable materials by a minimum distance of 20 ft (6.1 m) or by a building of non-combustible material at least 0.5 in (1.3 cm) thick. Cylinders should be kept away from electrical circuits or other sources of electrical sparking. Outlet seals should remain on cylinders not connected for use. Separate full from empty cylinders. Avoid excessive inventory and storage time. Use a first-in/first-out system. Keep good inventory records.

HANDLING: Do not drop, roll, or slide cylinder. Use a suitable handling device designed for cylinder movement. Never attempt to lift a cylinder by its cap. Secure cylinders at all times while in use. Use a pressure reducing regulator or separate control valve to safely discharge gas from cylinder. Use a check valve to prevent reverse flow into cylinder. Do not overload cylinder to increase pressure or discharge rate. Always open cylinder valve slowly. Do not use rapid opening valves (i.e., ball valves). If user experiences any difficulty operating cylinder valve, discontinue use and contact supplier. Never insert an object (e.g., wrench, screwdriver, pry bar, etc.) into valve cap openings. Doing so may damage valve causing a leak to occur. Use an adjustable strap wrench to remove over-tight or rusted caps.

All gauges, valves, regulators, piping, and equipment to be used in oxygen service must be cleaned for oxygen service in accordance with Compressed Gas Association pamphlet 0-4-1. Carbon steel, stainless steel, copper, brass, nickel and their alloys are materials of construction that can be used in oxygen service. Use piping and equipment adequately designed to withstand pressures to be encountered. Oxygen is not to be used as a substitute for compressed air. Never use an oxygen jet for cleaning purposes of any sort, especially clothing, as it increases the likelihood of an engulfing fire. Use a check valve or other protective apparatus in any line or piping from the cylinder to prevent reverse flow. When used in welding and cutting steel and other metals, the oxyacetylene flame should not be directed at the cylinder or its cap, valves, or regulators. Never release an arc on a compressed gas cylinder or make a cylinder part of an electrical circuit.

SPECIAL REQUIREMENTS: Always store and handle compressed gases in accordance with Compressed Gas Association, Inc. (pg. 703-412-0000) pamphlet CGA P-1. Safe Handling of Compressed Gases in Containers. Local regulations may require specific equipment for storage or use. CAUTION: Compressed gas cylinders shall not be returned except by qualified purchasers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with the owner's written consent is a violation of federal law.

SECTION 8. PERSONAL PROTECTION / EXPOSURE CONTROL

ENGINEERING CONTROLS: Provide ventilation and/or local exhaust to prevent accumulation of high concentrations of gas (greater than 2%):

RESPIRATORY PROTECTION:

GENERAL USE: None required

EMERGENCY: Use SCBA to prevent possibility of fire when concentrations exceed 2%.
SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

EPA - ENVIRONMENTAL PROTECTION AGENCY:

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980 requires notification to the National Response Center of releases of quantities of hazardous substances equal to or greater than the reportable quantities (RQ) in 40 CFR 302.4.

CERCLA Reportable Quantity: None

SARA TITLE III: Superfund Amendments and Reauthorization Act of 1986

SECTION 302: Requires emergency planning based on threshold planning quantities (TPQ) and release reporting based on reportable quantities (RQ) of EPA's extremely hazardous substances (40 CFR 302).

Oxygen is not listed as an Extremely Hazardous Substance.

SECTION 311/312: Requires submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification of EPA defined hazard classes. The hazard classes for this product are:

HAZARDS TO REACTIVITY: No

HAZARDS TO COMBUSTIBILITY / FLAMMABILITY: No

HAZARDS TO INCOMPATIBILITY: No

HAZARDS TO HEALTH EFFECTS: None

HAZARDOS DECOMPOSITION PRODUCTS: None

HAZARDOUS POLYMERIZATION: Will not occur

SECTION 10. REACTIVITY / STABILITY

Chemical Stability: Stable

Conditions to Avoid: None

Incompatibility: Oils, grease, hydrocarbons and flammable materials.

Hazardous Decomposition Products: None

Hazardous Polymerization: Will not occur

SECTION 11. PHYSICAL AND CHEMICAL PROPERTIES

Appearance: Colorless gas

Odor: Odorless

Molecular Weight: 32.0

Boiling Point (1 atm): -297.3°F (-183.0°C)

Specific Gravity (Air=1): 1.10

Specific Volume (at 70°F, 1 atm): 12.06 ft³/lb (0.754 m³/kg)

Freezing / Melting Point: 561.1°F (-216.8°C)

Vapor Pressure: Not applicable at 70°F

Gas Density (at 70°F, 1 atm and 1 ft³): 0.438 lb/ft³ (1.28 kg/m³)

Solubility in Water: Soluble at 21°C (70°F) - 0.048

SECTION 12. ECOLOGICAL INFORMATION

Atmospheric concentration and pressure. Oxygen poses no toxicity hazards.

Premature infants exposed to high oxygen concentrations may suffer delayed retinal damage which can progress to retinal detachment and blindness. Retinal damage may also occur in adults exposed to 100% oxygen for extended periods (24 to 48 hr).

At low or moderate atmospheric pressure, the CNS toxicity occurs. Symptoms include nausea, vomiting, dizziness or vertigo, muscle twitching, vision changes, and loss of consciousness and generalized seizures. At three atmospheres, CNS toxicity occurs in less than two hours, and at six atmospheres in only a few minutes.

SECTION 13. TOXICOLOGICAL INFORMATION

The atmosphere contains 21% oxygen. Various ecological effects are expected. Oxygen does not contain any Classes I or II ozone depleting chemicals. Oxygen is not listed as a marine pollutant by DOT (49 CFR 171).

SECTION 14. TRANSPORTATION

DOT HAZARD CLASS: 2.2 (Nonflammable Gas)

DOT SHIPPIING NAME: Oxygen, compressed

DOT SHIPPIING CODE: 02

IDENTIFICATION NUMBER: UN 1072

REPORTABLE QUANTITY: None

PLACARD: Nonflammable Gas or Oxygen
Ferrellgas Material Safety Data Sheet - Propane

SECTION 1: Emergency Information

24 Hour Emergency Number
Call 1-800-421-9590 (Collective) in case of emergency involving propane.

Warning!
Extremely flammable compressed gas.

- Avoid contact with liquid carbon tetrachloride.
- Use water spray to cool exposed equipment.

NIPA Hazard Rating
Hazard ratings are in the following table:

<table>
<thead>
<tr>
<th>Health Hazard</th>
<th>Fire Hazard</th>
<th>Reactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Where:
0 = Low
1 = Moderate
2 = Extreme

INHALATION: Remove victim to fresh air. If breathing stops, give artificial respiration. If breathing does not start, refer to section 6 for resuscitation procedures.

SAR Measurements

General MDES assistance: Call 6-790-700 and ask to speak with the Safety Department for general assistance with questions about this MDES.

SECTION 2: Hazardous Component/Identity Information

Product
Propane (polished)

Chemical name
Propane

Chemical family
Liquefied Petroleum Gas (Paraffinic Hydrocarbons)

Hazardous components
Propane may contain various percentages of these hazardous components, depending on the source of supply:

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>74-98-6</td>
<td>80 - 100</td>
</tr>
<tr>
<td>Propane Mixture</td>
<td>11518-1</td>
<td>0 - 33</td>
</tr>
<tr>
<td>Deodorant</td>
<td>124-38-4</td>
<td>0 - 7.5</td>
</tr>
<tr>
<td>Fillstock</td>
<td>74-44-0</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Ellipt Mixture</td>
<td>74-45-1</td>
<td>&lt;0.005%</td>
</tr>
</tbody>
</table>

Material Data Safety Sheet
**Section 4: Emergency and First Aid Procedures**

**Purpose**
Follow these procedures in case of personal injury resulting from use of this product.

**Eye contact with liquid**
Flush eye with water. Get medical attention.

**Skin contact with liquid**
Flush with water. If insensitive or burns occur, get medical attention.

**Inhalation**
Remove victim to fresh air and provide oxygen if breathing is difficult. Seek immediate medical attention if victim is not breathing. Give artificial respiration.

**Ingestion**
Not applicable to this product.

**Section 5: Physical Data**

**Physical properties**
Refer to this table for physical properties of this product.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance and odor</td>
<td>Odorless, gas, black under pressure, blue-green, &quot;vague cinnabar&quot; odor</td>
</tr>
<tr>
<td>Odor threshold (GHS)</td>
<td>1.5 (Allergic reaction)</td>
</tr>
<tr>
<td>Odor threshold (GHS)</td>
<td>1.5 (Allergic reaction)</td>
</tr>
<tr>
<td>Flash point</td>
<td>165 degrees F</td>
</tr>
<tr>
<td>Lower flammable vapor</td>
<td>1270</td>
</tr>
<tr>
<td>Minimum flammable range</td>
<td>200,000</td>
</tr>
<tr>
<td>Specific gravity (liquid)</td>
<td>0.900 - 0.906 (Water = 1)</td>
</tr>
<tr>
<td>Vapor pressure (atm)</td>
<td>195 (42.7°F 104°F)</td>
</tr>
</tbody>
</table>

**Section 6: Fire and Explosion Hazards**

**Flammability limits**
Flammability limits by volume are as follows:
- Lower 2.35 percent
- Upper 8.5 percent

**Ignition temperature**
Auto-ignition temperature is 940°F.

**Extinguishing agents**
Allow product to burn if source cannot be cut off safely.
- Class B-C or A-B-C dry chemical or halon extinguishers can be used on small fires.
- Apply water from a safe distance to cool containers, surrounding equipment, and structures.

**Section 3: Health Information**

**Purpose**
The health effects are consistent with requirements of the OSHA Hazard Communication Standard (29 CFR 1910.1200).

**Eye contact**
Direct contact with liquid product can result in eye burns.

**Skin contact**
Direct contact with liquid product can result in skin burns (Escharosis).

**Inhalation**
This product is classified as a simple asphyxiant. High vapor concentrations may produce reversible central nervous system depression (euphoria). Higher concentrations may produce asphyxiation.

**Ingestion**
Ingestion is not likely.

**Signs and symptoms**
Eye or skin burns (Escharosis) as noted previously.

**Acute or subacute danger**
Early respiratory depression may be evidenced by pallor, headache, hypotension, and unconsciousness. These symptoms may precede cardiac arrest.

**Aggravated medical conditions**
Caution is recommended for personnel with pre-existing cardiac or respiratory diseases.

**Acute toxicity data**
Acute toxicity data is not applicable to this product.

**Carcinogenicity**
This product is not classified as a carcinogen.

**Occupational exposure limits**
Use this table to determine the allowable exposure limits for personnel.

<table>
<thead>
<tr>
<th>TWA</th>
<th>OSHA</th>
<th>TLV-TWA</th>
<th>ACGIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500 PPm</td>
<td>Not established</td>
<td>500 PPm</td>
<td>Not established</td>
</tr>
</tbody>
</table>

**Cardiac effects**
No adverse health effects to occupational or substantial levels of hydrocarbons have been produced. Cardiac effects in humans, animal studies have shown that inhalation of high levels of the components of this product have produced cardiac sensitization. Such sensitization may cause arrhythmia changes in heart rhythm. This latter effect was shown to be enhanced by exposure to the injection of adrenaline-like agents.

**Effects of prolonged exposure**
Laboratory animals exposed to high levels of propylene for prolonged periods of time showed evidence of effects in the liver, kidneys, and central nervous system.
Section 6: Fire and Explosion Hazards, Continued

Special fire fighting precautions and precautions

Evacuate surrounding areas of any exposed personnel and isolate. Do not enter confined fire spaces without full body gear (helmet with face shield, booties and gloves, and either boots or a positive pressure NIOSH approved self-contained breathing apparatus).

Section 7: Reactivity

Stability and reactivity polymers and products

This product is stable. Hazards polymerization will not occur.

Conditions and materials to avoid

Avoid heat, smoke, flame and contact with strong oxidizing agents. Avoid buildup of static electricity.

Prevent vapor accumulation


Section 8: Employee Protection

Respiratory protection

Use a NIOSH approved respirator as required when airborne exposure limits are exceeded. Use an atmosphere supplying respirator or a non-feeding respirator for organic vapors.

Protective clothing

Avoid liquid contact with eyes or skin.

Wear safety glasses or goggles as appropriate.

Wear protective clothing as appropriate.

Additional protective measures

Use explosion-proof ventilation or explosion-proof exhaust systems.

Section 9: Precautions For Safe Handling and Use

Release spill or leak procedures

Warning: Extremely flammable.

Eliminate sources of ignition.

Isolate released area and deny entry to unnecessary or unprotected personnel.

Keep away and keep out of fire areas.

Do not exceed the exposure concentration

Use approved respirator with water sprays.

Check off source of leak only if it can be done safely.
MATHESON TRI-GAS

MATERIAL SAFETY DATA SHEET

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MATHESON TRI-GAS, INC.
150 Allen Road Suite 302
Basking Ridge, New Jersey 07920
Information: 1-800-416-2505

Emergency Contact: CHEMTRAC 1-800-424-9360
Calls Originating Outside the U.S.:
703-527-3887 (Collect Calls Accepted)

SUBSTANCE: PROPYLENE

TRADE NAMES/SYNONYMS:
MTG MDS# 77; PROPANE, METHYLTHIENE, METHYLMETHYLENE, 1-PROPYLENE, 1-PROPANE,
UN 1077; C1116; MARYNOL; RTECS UY400000

CHEMICAL FAMILY: hydrocarbons, aliphatic

CREATION DATE: Jan 24 1989
REVISION DATE: Dec 11 2008

2. COMPOSITION INFORMATION ON INGREDIENTS

COMPONENT: PROPYLENE
CAS NUMBER: 115-97-1
PERCENTAGE: 100.0

3. HAZARDS IDENTIFICATION

NFPA RATINGS (SCALE 0-4): HEALTH=1 FIRE=4 REACTIVITY=1

EMERGENCY OVERVIEW:
COLOR: colorless
PHYSICAL FORM: gas
MAJOR HEALTH HAZARDS: central nervous system depression, difficulty breathing
PHYSICAL HAZARDS: Flammable gas. May cause flash fire.

POTENTIAL HEALTH EFFECTS:
INHALATION:
SHORT TERM EXPOSURE: tearing, nausea, vomiting, symptoms of dizziness, suffocation, convulsions, coma
LONG TERM EXPOSURE: no information on significant adverse effects

Section 11: Other Regulatory Controls

EPA TSCA The components of this product are listed on the EPA TSCA Inventory of Chemical Substances.

EPA Hazard Classification
This product is classified by 49 CFR Part 172 (Hazardous Materials Table) as:
Acute Hazard: Ocean Hazard: Fire Hazard: Presence Hazard: Reactivity Hazard:
XXA: XXA: XXX: XXX: XXX: XXX:

Ozone-depleting substances
This product does not contain any ozone depleting substances.

RCRA Information
This product is not subject to 40 CFR Part 261. It has no hazardous wastes.

Storage Information
If this product becomes a waste material, it would be an ignitable hazardous waste, having a waste code number D000. Refer to the EPA or state regulations regarding proper disposal. Under the EPA RCRA, containers are considered hazardous wastes if dispersed into the atmosphere or a pressurized container at a controlled rate to a flammable vapor.

More regulatory information
The requirements in this product are specifically listed by individual states; other product specific health and safety data in other sections of the MSDS may also be applicable for state requirements.

Contact the appropriate agency in your state for details on your regulatory requirements.

California Proposition 65 Warning
Chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm are contained by the combination of propylene.
6. ACCIDENTAL RELEASE MEASURES

OCCUPATIONAL RELEASE:

7. HANDLING AND STORAGE


8. EXPOSURE CONTROLS, PERSONAL PROTECTION

EXPOSURE LIMITS:
PROPYLENE:
500 ppm ACGIH TWA

VENTILATION: Ventilation equipment should be explosion-resistant if explosive concentrations of material are present. Provide local exhaust ventilation system. Ensure compliance with applicable exposure limits.

EYE PROTECTION: For the gas: Eye protection not required, but recommended. For the liquid: Wear splash resistant safety goggles. Contact lenses should not be worn. Provide an emergency eye wash fountain and quick drench shower in the immediate work area.

CLOTHING: For the gas: Protective clothing is not required. For the liquid: Wear appropriate protective, cold-resistant clothing.

GLOVES: Wear non-irritating gloves.

RESPIRATOR: Under conditions of frequent use or heavy exposure, respiratory protection may be needed. Respiratory protection is ranked in order from minimum to maximum. Consider warning properties before

9. FIRST AID MEASURES

INHALATION: If symptoms occur, remove to unobstructed area. Give artificial respiration if not breathing; if breathing is difficult, oxygen should be administered by qualified personnel. Get immediate medical attention.

SKIN CONTACT: For gas or liquid, immediately flush with plenty of lukewarm water (105-115 F, 41-46 C). DO NOT USE HOT WATER. If warm water is not available, gently wrap affected parts in icepacks. Get immediate medical attention.

EYE CONTACT: For liquid: Immediately flush eyes with plenty of water for at least 15 minutes. Then get immediate medical attention.

INGESTION: If a large amount is swallowed, get medical attention.

NOTE TO PHYSICIAN: For inhalation, consider oxygen.

5. FIRE FIGHTING MEASURES

FIRE AND EXPLOSION HAZARDS: Severe fire hazard. Vaporizer mixtures are explosive above flash point. The vapor is heavier than air. Vapors or gas may ignite at distant ignition sources and flash back. Electrostatic discharges may be generated by flow or agitator resulting in ignition or explosion.

EXTINGUISHING MEDIA: Carbon dioxide, regular dry chemical.

Large fires: Flood with fire water spray.

FIRE FIGHTING: Move containers from fire area if it can be done without risk. Cool containers with water spray until well after the fire is out. Stay away from the ends of tanks. For fires in cargo or storage area, Cool containers with water from unburned hose holder or moveable nozzle until well after fire is out. If this is impossible, form like the following procedures: Keep unnecessary people away, isolate heated area and deny entry. Let the fire burn. Withdraw immediately in case of rising sound from venting safety device or any disorientation of tanks due to fire. For tank, rail car or tank truck, stop leak if possible without personal risk. Let burn unless leak can be stopped immediately. For similar tanks or cylinders, extinguish and isolate from
11. TOXICOLOGICAL INFORMATION

PROPYLENE:
CARCINOGENIC STATUS: Human Inadequate Evidence, Animal Inadequate Evidence, Group 3; ACCIG: A4 - Not Classifiable as a Human Carcinogen
TARGET ORGAN: Central nervous system
MUTAGENIC DATA: Available
ADDITIONAL DATA: Monotherapy such as epinephrine may induce ventricular fibrillation

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE: gas
COLOR: colorless
ODOR: Not available
MOLECULAR WEIGHT: 42.08
BOILING POINT: -53 °F (-47 °C)
FREEZING POINT: -201 °F (-185 °C)
VAPOR PRESSURE: 7628 mmHg at 21.1 °C
VAPOR DENSITY: air = 1; 1.5
SPECIFIC GRAVITY: Not applicable
DENSITY: 1.785 g/L
WATER SOLUBILITY: 45%
PH: Not applicable
VOLATILITY: Not applicable
ODOR THRESHOLD: Not available
EVAPORATION RATE: Not applicable
VISCOSITY: 0.140 cP @ -90 °C
COEFFICIENT OF WATER DISSOLUTION: Not applicable
SOLVENT SOLUBILITY: Soluble: acetic acid, ether, acetic acid

10. STABILITY AND REACTIVITY

REACTIVITY: May polymerize. May react on contact with air, heat, light or water.
CONDITIONS TO AVOID: Avoid heat, flames, sparks and other sources of ignition. Minimize contact with material. Containers may rupture or explode if exposed to heat.
INCOMPATIBILITIES: oxidizing materials, halo compounds, biologens, acids
HAZARDOUS DECOMPOSITION: Thermal decomposition products: miscellaneos decomposition products
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifier

Product name: Zirconium(V) oxide-yttria stabilized
Product Number: 572340
Brand: Aldrich

CAS-No: 11418-19-0

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

Identified uses: Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company: Sigma-Aldrich
Address: 3670 Spruce Street
City: St Louis MO
Postal Code: 63110
USA

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

1.4 Emergency telephone number

Emergency Phone #: (314) 776-0555

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Eye irritation (Category 2A), H319
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335

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

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Warning
Hazard statement(s): Causes skin irritation. Causes serious eye irritation. May cause respiratory irritation.
Precautionary statement(s): P261 Avoid breathing dust, fume, gas, mist, vapours or spray. P264 Wash skin thoroughly after handling. P271 Use only outdoors or in a well-ventilated area. P280 Wear protective gloves and eye protection/face protection. P302 + P352 IF ON SKIN: Wash with plenty of soap and water. P304 + P340 IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses if present and easy to do so.
5.2 Special hazards arising from the substance or mixture
Zinc oxide, Yttrium oxides

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

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.

For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Provide appropriate exhaust ventilation at places where dust is formed. For precautions see section 2.2.

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

Keep in a dry place.

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

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters
Components with workplace control parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yttrium oxide</td>
<td>1344-36-0</td>
<td>TWA</td>
<td>1.000000 mg/m³</td>
<td>USA, ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Remarks</td>
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<tr>
<td></td>
<td></td>
<td>Primary Exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>1 mg/m³</td>
<td>USA, ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Primary Exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>1.000000 mg/m³</td>
<td>USA, NIOSH Recommended Exposure Limits</td>
</tr>
</tbody>
</table>

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

Personal protective equipment
Eye/face protection
Safety glasses with side-shields conforming to EN166. Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166 (EU).

P312 Call a POISON CENTER or doctor/physician if you feel unwell.
P311 If you feel unwell. Get medical advice immediately.
P313 Call a POISON CENTER if you feel unwell.
P314 Take off contaminated clothing and wash before reuse.
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P405 Store locked up.
P501 Dispose of contents/container to an approved waste disposal plant.

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

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances
Symptoms: YES
Form: Ogy52R
Molar weight: 546.03 (g/mol)
CAS-No: 11418-16-0

Hazardous components:

Component | Classification | Concentration
-----------|----------------|-------------
Yttrium oxide | Skin Irrit. 2; Eye Irrit. 2; STOT SE 3; H315, H336, H360 | <= 100 %

No components need to be disclosed according to the applicable regulations. For the full text of the 16 Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

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

Inhalation
If inhaled, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.
In case of skin contact
Wash with soap and plenty of water. Consult a physician.
In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

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

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

5. FIREFIGHTING MEASURES

5.1 Extinguishing media
Suitable extinguishing media
Water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

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STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions. Contain the following statement(s):
Ybrium oxide (5%)

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

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

TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Skin:
No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

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

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

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

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

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
No data available

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

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

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particulate respirator. For higher level protection use type OVAG/99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance
Powder

b) Odour
No data available

c) Odour Threshold
No data available

d) pH
No data available

e) Melting point/freezing point
Melting point range: > 26 °C (70 °F) - 71 °C

f) Initial boiling point and boiling range
No data available

g) Flash point
Not applicable

h) Explosion range
No data available

i) Flammability (solid, gas)
No data available

j) Upper/lower flammability or explosive limits
No data available

k) Vapour pressure
No data available

l) Vapour density
No data available

m) Relative density
No data available

n) Water solubility
No data available

o) Partition coefficient octanol/water
No data available

p) Auto-ignition temperature
No data available

q) Decomposition temperature
No data available

r) Viscosity
No data available

s) Explosive properties
No data available

t) Oxidising properties
No data available

9.2 Other safety information
No data available
SARA 313/312 Hazards
Acute Health Hazard
Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.
Pennsylvania Right To Know Components
Yttrium oxide
CAS-No: 1314-36-9
Revision Date: 11/16/96
New Jersey Right To Know Components
Yttrium oxide
CAS-No: 1314-36-9
Revision Date: 11/16/96
California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

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

Eye irritation:
H315 Causes skin irritation.
H319 Causes serious eye irritation.
S35 May cause respiratory irritation.
Skin irritation:
STOT GE Specific target organ toxicity - single exposure

HIMS Rating:
Health hazard: 2
Chronic Health Hazard: 1
Physical Hazard: 0

NFPA Rating:
Health Hazard: 2
Fire Hazard: 0
Reactivity Hazard: 0

Further Information
Copyright 2015 Sigma-Aldrich Co. LLC. License granted to make unlimited paper copies for internal use only. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliate shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product SMLY – Ametsa Region
1-800-521-8698

Specific target organ toxicity - repeated exposure
No data available
Aspiration hazard
No data available
Additional Information
RTECS: Not available
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION
12.1 Toxicity
No data available
12.2 Persistence and degradability
No data available
12.3 Bioaccumulative potential
No data available
12.4 Mobility in soil
No data available
12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted
12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS
13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.
Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION
DOT (US)
Not dangerous goods
IMDG
Not dangerous goods
IATA
Not dangerous goods

15. REGULATORY INFORMATION
SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.
SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.
P364  Wash skin thoroughly after handling.
P370  Do not eat, drink or smoke when using this product.
P371  Use only outdoors or in a well-ventilated area.
P380  Wear protective gloves and eye protection/face protection.
P390 + P312 + P330  IF SWALLOWED: Call a POISON CENTER or doctor/physician if you feel unwell. Rinse mouth.
P390 + P362  IF ON SKIN: Wash with plenty of soap and water.
P390 + P340 + P312  IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/physician if you feel unwell.
P390 + P351 + P338  IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses. If present and easy to do. Continue rinsing.
P332 + P313  If skin irritation occurs: Get medical advice/attention.
P337 + P313  If eye irritation persists: Get medical advice/attention.
P338 + P373  Take off contaminated clothing and wash before reuse.
P360 + P330  In case of fire: Use dry sand, dry chemical or alcohol resistant foam for extinction.
P405 + P335  Store in a cool, well-ventilated place. Keep container tightly closed.
P451  Store locked up.
P531  Dispose of contents/container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (H335) or not covered by GHS - none.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc nitrate hydrate</td>
<td>On Site, 2 Acute Tor 4, Skin Irrit 3, Eye Irr 3a, STOT SE 3 H272, H302, H315, H319, H335</td>
<td>100 %</td>
</tr>
</tbody>
</table>

For the full list of the H-Stations mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

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

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

If in contact with skin
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician. Continue rinsing eyes during transport to hospital.

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

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

SIGMA-ALDRICH

SAFETY DATA SHEET

Version 3.6
Revision Date 11/15/2017
First Print Date 04/05/2016

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name: Zinc nitrate hydrate

Product Number: 06482

Brand: Sigma-Aldrich

CAS-No: 10196-18-6

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

Identified uses: Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company: Sigma-Aldrich

3001 Spruce Street

Philadelphia, PA 19104 USA

Telephone: +1 800-325-3832

Fax: +1 800-325-6522

1.4 Emergency telephone number

Emergency Phone #: (314) 776-6555

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)

G303/321/223: Skin sensitizer. Category 2, H316

Eye irritation (Category 2A), H315

2.2 GHS Label elements, including precautionary statements

Picture

Signal word: Danger

Hazard statement(s):
H372 May cause serious eye irritation.

P210 Keep out of reach of children.

P220 Keep/Store away from clothing/combustible materials.

Precautionary statement(s):
P201 Keep away from heat.

P221 Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.

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Personal protective equipment

By the exercises:
- Use gloves with side-seals conforming to EN165 (Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 169 (EU)).

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

Full contact
- Material: Nitrile rubber
- Minimum layer thickness: 0.11 mm
- Breakthrough time: 480 min
- Material tested: Detergent (KCL 7451-3367272, Size M)
- Spleen contact
- Material: Nitrile rubber
- Minimum layer thickness: 0.11 mm
- Breakthrough time: 480 min
- Material tested: Detergent (KCL 7451-33672727, Size M)

Data source: KOL Oderdr. 1 30-124 Essen, phone +49 (0)2059 67300, e-mail sales@kcl.de, test method EN374

If used in solution, mixed with other substances, and under conditions which differ from the EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for specific use scenarios.

Respiratory protection
- Complete suit protecting against chemicals. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

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

Respiratory protection
- Where risk assessment shows air-purifying respirators are appropriate, use a full-face particulate respirator type N100 (US) or type P3 (EN 149) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and contaminants tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
- Do not let product enter drains.

3. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance
- Form: crystalline
- Colour: brown

b) Odour
- No data available

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

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

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

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

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
Infantilization - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure
No data available

Absorption hazard
No data available

Additional information
KTECS: 29K47BSKZ

Fever, Cough, Nausea, Vomiting, Weakness

Stomach - Irritability - Based on Human Evidence

Stomach - Irritability - Based on Human Evidence

12. ECOLOGICAL INFORMATION
12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

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

12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS
13.1 Waste treatment methods
Product
Benz in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and recovers solvents to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dispose of the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as unused product.

explosive limits
k) Vapour pressure
No data available

l) Vapour density
2.065 g/m3

m) Relative density
No data available

n) Water solubility
No data available

o) Partition coefficient n-octanol/water
No data available

p) Auto-ignition temperature
No data available

q) Decomposition temperature
No data available

r) Viscosity
No data available

s) Explosive properties
No data available

T) Oxidizing properties
The substance or mixture is classified as oxidizing with the category 2.

5.2 Other safety information
No data available

10. STABILITY AND REACTIVITY
10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Hygroscopic

10.5 Incompatible materials
Powdered metals, Cyanides, Sodium hypochlorite, Sulfuric chloride, Thiocyanates, Strong reducing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available

In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION
11.1 Information on toxicological effects
Acute toxicity
LC50 Oral - Rat: 1.19 g/m3

Dermal: No data available

No data available

Skin corrosion/irritation
Skin - Rabbit

Result: Severe skin irritation - 24 h

Serious eye damage/eye irritation
Eyes - Rabbit

Result: Moderate eye irritation - 24 h

Respiratory or skin sensitisation
No data available

Genetic cell mutagenicity
No data available

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Chronic Health Hazard:  
Flammability: 0  
Physical Hazard: 2

NFPA Rating:  
Health hazard: 3  
Fire hazard: 0  
Reactivity hazard: 2 
Special hazard: OX

Further Information  
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Preparation Information  
Sigma-Aldrich Corporation  
Product Safety – Americas Region  
1-800-521-4856

Version: 3.5  
Revision Date: 11/16/2014  
Print Date: 04/01/2016

14. TRANSPORT INFORMATION  
DOT (US)  
UN number: 1544  
Class: 5.1  
Packing group: II  
Proper shipping name: Zinc nitrate  
Reportable Quantity (RQ): 1000 lbs  
Poison Inhalation Hazard: No

IMDG  
UN number: 1544  
Class: 5.1  
Packing group: II  
EMS-No: F+1, S-Q

IATA  
UN number: 1544  
Class: 5.1  
Proper shipping name: Zinc nitrate  
Packing group: II

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

SARA 313 Components  
The following components are subject to reporting levels established by SARA Title III, Section 313:  
CAS-No: 10196-15-6  
Revision Date: 1993-04-24

SARA 311/312 Hazards  
Reactivity hazard, acute health hazard, chronic health hazard

Massachusetts Right To Know Components  
Zinc nitrate heptahydrate  
CAS-No: 10196-15-6  
Revision Date: 1993-04-24

Pennsylvania Right To Know Components  
Zinc nitrate heptahydrate  
CAS-No: 10196-15-6  
Revision Date: 1993-04-24

New Jersey Right To Know Components  
Zinc nitrate heptahydrate  
CAS-No: 10196-15-6  
Revision Date: 1993-04-24

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

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

Acute Tox.  
Acute toxicity

Eye Irrit.  
Eye irritation

H272  
May intensify fire or explosion.

H312  
Harmful if swallowed.

H315  
Causes skin irritation.

H319  
Causes serious eye irritation.

H335  
May cause respiratory irritation.

G2: St  
Grinding solids

5: Skin Irr.  
Skin irritation

HMS Rating  
Health hazard: 3