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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Propane Dehydrogenation by Autothermal Reforming

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 .2-.6%Pt- Sn/ZnAl₂O₅ 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
April 12, 2015

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
Propane Dehydrogenation by Autothermal Reforming

Senior Design Project, CBE 459
Project submitted to: Dr. Raymond Gorte
Prof. Leonard Fabiano
Project proposed by: Mr. John Wismer

Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Science
University of Pennsylvania
April 12, 2016
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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/ZnAl₂O₅ 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 as a byproduct 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 oxydehydrogenation 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 CO$_2$ 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 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: In 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
News, 2015). 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 convers 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 Intratec, 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 (Intratec). 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.
Preliminary Process Synthesis

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 (Herauville, 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 reach 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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<td>Oxygen</td>
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<td>Propene</td>
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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
- HX-Heat Exchanger
- P-Pump
- RB-Reboiler
- C-Compressor
- DC-Distillation Column
- RA-Reflux Accumulator
- CN-Condenser
- AB-Absorption Column
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:

\[ C_3H_8 \rightarrow C_3H_6 + H_2 \]  \hspace{1cm} (1)

\[ C_3H_8 \rightarrow C_2H_4 + CH_4 \]  \hspace{1cm} (2)

\[ C_3H_8 + H_2 \rightarrow C_2H_6 + CH_4 \]  \hspace{1cm} (3)
\[ C_3H_8 + 2 H_2 \rightarrow 3 CH_4 \] \hspace{1cm} (4)

\[ CH_4 \rightarrow C + 2 H_2 \] \hspace{1cm} (5)

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:

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

\[ C_3H_8 + 5 O_2 \rightarrow 3 CO_2 + 4 H_2O \] \hspace{1cm} (7)

\[ C_3H_6 + \frac{9}{2} O_2 \rightarrow 3 CO_2 + 3 H_2O \] \hspace{1cm} (8)

\[ CH_4 \rightarrow C + 2 H_2 \] \hspace{1cm} (9)

\[ 2 CO \rightarrow C + CO_2 \] \hspace{1cm} (10)

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

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

\[ C_3H_8 + 3 H_2O \rightarrow 3 CO + 7 H_2 \]
Propylene has a lower selectivity in the oxydehydrogenation reactors of 88% with a CO\textsubscript{x} 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 stream 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 H\textsubscript{2} 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.

H\textsubscript{2} 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*10\textsuperscript{8} 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*10\textsuperscript{4} 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*10^8 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*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*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 55F Seider et, al. The total cooling water energy necessary for the process is 2.68*10^5 GJ/year.
HX-101 reduces the temperature of the oxyreactor effluent S-113 from 1211°F to S-201’s temperature of 461°F. At the same time, the feed to the reformers is increased from 288°F to 1094°F, 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 1211°F to S-201’s temperature of 461°F. At the same time, the feed to the reformers is increased from 288°F to 1094°F, 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.

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<th>Unit</th>
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<th>Utility Cost ($ per unit)</th>
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### Table 3: Detailed Utility Requirements for All Units

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<td>Cooling Water</td>
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<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>
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<tr>
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<td>4.12E+10</td>
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</table>

<table>
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<tr>
<th>Utility Name</th>
<th>Process Unit</th>
<th>Quantity (GJ/yr)</th>
</tr>
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<tr>
<td>Chilled Water</td>
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<td>2.68E+05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>2.68E+05</td>
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</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 ft$^3$ 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 ft$^2$. 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 ft$^2$. 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 ft\(^2\). 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.
### DISTILLATION COLUMN

<table>
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<tr>
<th>Identification: Item</th>
<th>Distillation Column No.</th>
<th>Item No.</th>
<th>No. Required</th>
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<tbody>
<tr>
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<td>DC-202</td>
<td>S-208</td>
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**Function:** Remove hydrogen, carbon monoxide and light components

**Operation:** Continuous

**Type:** N/A

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

| Flow rate (lb/hr) | 418,458 | 406,818 | 11,640 |
| Temperature (°F)  | 424     | 125     | -96    |
| Pressure (psia)   | 300     | 282     | 270    |

**Composition (lb/hr):**

- **Propane:** 213,634, 213,575, 60
- **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
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<th>Identification:</th>
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<td>Pump the contents of the reflux accumulator back to DC-202</td>
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<td>Design Data:</td>
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<td>Type:</td>
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<td>Material:</td>
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<td>REBOILER PUMP</td>
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<td></td>
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<tr>
<td>Identification:</td>
<td>P-205</td>
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<tr>
<td>Function:</td>
<td>Increase pressure in the reboiler RB-202</td>
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<td>Operation:</td>
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<td>Design Data:</td>
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<td>Total Bare Module Cost</td>
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<tr>
<td>Identification:</td>
<td>RA-202</td>
</tr>
<tr>
<td>Function:</td>
<td>Accumulate reflux in DC-202</td>
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<tr>
<td>Operation:</td>
<td>continuous</td>
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<td><strong>Design Data:</strong></td>
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<td>Type:</td>
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<td>Material:</td>
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<td>Diameter (ft):</td>
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<td>Residence Time (min):</td>
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<tr>
<td><strong>Total Bare Module Cost</strong></td>
<td><strong>$295,000.00</strong></td>
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## CONDENSER

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

### Design Data:

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<th>Type:</th>
<th>Shell &amp; Tube</th>
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<tbody>
<tr>
<td>Subtype:</td>
<td>Fixed Head</td>
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<td>Material:</td>
<td>Carbon Steel</td>
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<tr>
<td>Length (ft.):</td>
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<tr>
<td>Area (ft^2):</td>
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<td>Condenser Duty (MMBTU):</td>
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<td>Condenser Pressure (psia):</td>
<td>270</td>
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<table>
<thead>
<tr>
<th>Utilities (cooling Water)</th>
<th>$</th>
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<tbody>
<tr>
<td>Total Bare Module Cost</td>
<td>$</td>
<td>1,200,000.00</td>
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## REBOILER

<table>
<thead>
<tr>
<th>Identification:</th>
<th>RB-202</th>
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</thead>
<tbody>
<tr>
<td>Function:</td>
<td>Vaporize bottoms of DC-202</td>
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<tr>
<td>Operation:</td>
<td>Continuous</td>
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### Design Data:

<table>
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<tr>
<th>Type:</th>
<th>Shell &amp; Tube</th>
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<tbody>
<tr>
<td>Subtype:</td>
<td>Kettle Vaporizer</td>
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<tr>
<td>Material:</td>
<td>Carbon Steel</td>
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<tr>
<td>Length(ft):</td>
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</tr>
<tr>
<td>Area (ft²):</td>
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<tr>
<td>Reboiler Duty (MMBTU):</td>
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| Total Bare Module Cost | $2,100,000.00 |
# DISTILLATION COLUMN

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<tr>
<th>Identification:</th>
<th>Item</th>
<th>Distillation Column</th>
</tr>
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<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>DC-500</td>
</tr>
<tr>
<td>No. Required</td>
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**Function:** To provide an initial separation of propene from propane.

**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-501</td>
<td>S-503</td>
<td>S-502</td>
</tr>
<tr>
<td>Flow rate (lb/hr)</td>
<td>407675</td>
<td>125287</td>
<td>282388</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>125</td>
<td>121</td>
<td>103</td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>282</td>
<td>245</td>
<td>225</td>
</tr>
</tbody>
</table>

**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>0.000134751</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:**

<table>
<thead>
<tr>
<th>Column Diameter (ft):</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material of Constructon:</td>
<td>Carbon Steel</td>
</tr>
<tr>
<td>Number of Stages:</td>
<td>90</td>
</tr>
<tr>
<td>Feed Stage:</td>
<td>45</td>
</tr>
<tr>
<td>Reflux Ratio:</td>
<td>5</td>
</tr>
<tr>
<td>Boilup Ratio:</td>
<td>14.13</td>
</tr>
</tbody>
</table>

**Cost of utilities/year:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>$3,435,000</td>
</tr>
<tr>
<td>Cooling water</td>
<td>$1,195,000.00</td>
</tr>
<tr>
<td>Electricity</td>
<td>$204,000.00</td>
</tr>
</tbody>
</table>

**Purchase Cost:** $10,875,000.00

**Bare Module Cost:** $45,240,000.00

**Associated Costs:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser</td>
<td>$1,066,000.00</td>
</tr>
<tr>
<td>Reboiler</td>
<td>$7,458,867.00</td>
</tr>
<tr>
<td>Reboiler Pump</td>
<td>$19,000.00</td>
</tr>
<tr>
<td>Reflux Accumulator</td>
<td>$1,172,000.00</td>
</tr>
<tr>
<td>Reflux Pump</td>
<td>$80,000.00</td>
</tr>
</tbody>
</table>

**Total Bare Module Cost:** $55,035,867.00

**Comments:**

DISTILLATION COLUMN

Identification:

To provide an initial separation of propene from propane.

Continuous

N/A

Feed

S-501

Bottoms

S-503

Overhead

S-502

Flow rate (lb/hr):

407675

125287

282388

Temperature (°F):

125

121

103

Pressure (psia):

282

245

225

Composition (lb/hr):

Propane

213575

124413

89162.01

Propene

193699

484

193216

Hydrogen

0.000134751

0

0

Oxygen

0

0

0

Water

390

390

0

Carbon Monoxide

0.02

0

0.02

Carbon Dioxide

2.54

0

2.54

Methane

0.03

0

0.03

Ethane

6.3

0

6.3

Ethene

2

0

2

Design Data:

Column Diameter (ft):

30

Material of Constructon:

Carbon Steel

Number of Stages:

90

Feed Stage:

45

Reflux Ratio:

5

Boilup Ratio:

14.13

Cost of utilities/year:

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>$3,435,000</td>
</tr>
<tr>
<td>Cooling water</td>
<td>$1,195,000.00</td>
</tr>
<tr>
<td>Electricity</td>
<td>$204,000.00</td>
</tr>
</tbody>
</table>

Purchase Cost:

$10,875,000.00

Bare Module Cost:

$45,240,000.00

Associated Costs:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser</td>
<td>$1,066,000.00</td>
</tr>
<tr>
<td>Reboiler</td>
<td>$7,458,867.00</td>
</tr>
<tr>
<td>Reboiler Pump</td>
<td>$19,000.00</td>
</tr>
<tr>
<td>Reflux Accumulator</td>
<td>$1,172,000.00</td>
</tr>
<tr>
<td>Reflux Pump</td>
<td>$80,000.00</td>
</tr>
</tbody>
</table>

Total Bare Module Cost:

$55,035,867.00

Comments:
# 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>
</tbody>
</table>

## Design Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Centrifugal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Cast Iron</td>
</tr>
<tr>
<td>Flow Rate (gpm)</td>
<td>7086</td>
</tr>
<tr>
<td>Head (ft)</td>
<td>337</td>
</tr>
<tr>
<td>Rating</td>
<td>368KW</td>
</tr>
</tbody>
</table>

Utilities Electricity  $  188,942.00

Total Bare Module Cost  $  79,630.00
## 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>

### Design Data:

<table>
<thead>
<tr>
<th>Type:</th>
<th>Centrifugal</th>
</tr>
</thead>
<tbody>
<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>
</tr>
</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>
</tbody>
</table>

### Design Data:

<table>
<thead>
<tr>
<th>Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material:</td>
</tr>
<tr>
<td>Diameter (ft):</td>
</tr>
<tr>
<td>Length (ft):</td>
</tr>
<tr>
<td>Capacity (ft³):</td>
</tr>
<tr>
<td>Residence Time (min):</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Bare Module Cost</th>
<th>$1,172,213.00</th>
</tr>
</thead>
</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>
<tr>
<td>Design Data:</td>
<td></td>
</tr>
<tr>
<td>Type:</td>
<td>Shell &amp; Tube</td>
</tr>
<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 (ft^2)</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**

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

**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>

<table>
<thead>
<tr>
<th>Flow rate (lb/hr)</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>423494</td>
<td>N/A</td>
<td>418458</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>176</td>
<td>N/A</td>
<td>176</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure (psia)</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
<td>N/A</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Composition (lb/hr)</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>213634</td>
<td>N/A</td>
<td>213634</td>
</tr>
<tr>
<td>Propene</td>
<td>194983</td>
<td>N/A</td>
<td>194983</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>6697</td>
<td>N/A</td>
<td>6690</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>548</td>
<td>N/A</td>
<td>389</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>1635</td>
<td>N/A</td>
<td>1635</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>5181</td>
<td>N/A</td>
<td>311</td>
</tr>
<tr>
<td>Methane</td>
<td>287</td>
<td>N/A</td>
<td>287</td>
</tr>
<tr>
<td>Ethane</td>
<td>247</td>
<td>N/A</td>
<td>247</td>
</tr>
<tr>
<td>Ethene</td>
<td>281</td>
<td>N/A</td>
<td>281</td>
</tr>
</tbody>
</table>

**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:** Adsorption Column

<table>
<thead>
<tr>
<th>Item No.</th>
<th>No. Required</th>
<th>Function</th>
<th>Operation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Remove water from reactor effluent prior to C3 separation</td>
<td>Continuous</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stream ID</th>
<th>Feed</th>
<th>Bottoms</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-204</td>
<td>432420</td>
<td>422025</td>
<td>10395.36</td>
</tr>
<tr>
<td>S-213</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-205</td>
<td>176</td>
<td>176</td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>34.8</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>213,634</td>
<td>0</td>
<td>213,634</td>
</tr>
<tr>
<td></td>
<td>194,983</td>
<td>0</td>
<td>194,983</td>
</tr>
<tr>
<td></td>
<td>6,697</td>
<td>0</td>
<td>6,697</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>109,671</td>
<td>10418</td>
<td>548</td>
</tr>
<tr>
<td></td>
<td>1635</td>
<td>0</td>
<td>1,635</td>
</tr>
<tr>
<td></td>
<td>5,181</td>
<td>0</td>
<td>5,181</td>
</tr>
<tr>
<td></td>
<td>290</td>
<td>2.9</td>
<td>287</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>2.5</td>
<td>247</td>
</tr>
<tr>
<td></td>
<td>281</td>
<td>0</td>
<td>281</td>
</tr>
</tbody>
</table>

**Cost of utilities/year:**

- Electricity: $28,350.00
- Nitrogen (purge): $333,000.00
- Chilled Water: $1,340,000.00
- Natural Gas: $27,700.00
- Total cycle time (hr): 8
- Regeneration time (hr): 7
- Transition Time (hr): 1

**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

<table>
<thead>
<tr>
<th><strong>Identification:</strong></th>
<th>Item</th>
<th>Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>C-201</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Function:** Compress air before cryogenic distillation

**Operation:** Continuous

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

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

- **Air Flow Rate (lb/hr)**: 418458
- **Temperature (°F)**: 176 (In) | 294 (Out)
- **Pressure (psi)**: 35 (In) | 100 (Out)

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

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

**Purchase Cost:**
- **$3,100,000.00**

**Bare Module Cost:**
- **$7,130,000.00**

**Comments:** Bare Module cost includes interstage cooling using recycled chilled water
<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item</th>
<th>Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>C-202</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></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>
</table>

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>294</th>
<th>423</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>100</th>
<th>300</th>
</tr>
</thead>
</table>

**Design Data:**

- Construction Material: Carbon Steel
- Consumed (Hp): 12,321
- Drive Type: Electric Motor Drive
- 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:**

- $3,700,000.00$

**Bare Module Cost:**

- $8,510,000.00$

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

<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>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>93.6754</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>20</td>
</tr>
</tbody>
</table>

**Design Data:**

<table>
<thead>
<tr>
<th>Construction Material:</th>
<th>Cast Iron/Carbon-Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (Hp):</td>
<td>7,411</td>
</tr>
<tr>
<td>Drive Type:</td>
<td>Electric Motor Drive</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost of utilities/year:</th>
<th>Electricity</th>
<th>$3,388,000.00</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Purchase Cost:</th>
<th>$2,442,000.00</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Bare Module Cost:</th>
<th>$5,251,000.00</th>
</tr>
</thead>
</table>

**Comments:** COMPRESSOR
## 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-501</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**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 (ºF)      | 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
- **$1,424,000.00**
- **$3,062,000.00**

**Comments:**
- COMPRESSOR
- Purchase Cost: Bare Module Cost:
### TURBINE

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

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

**Purchase Cost:** $795,000.00  
**Bare Module Cost:** $1,431,000.00
<table>
<thead>
<tr>
<th>Identification</th>
<th>Item</th>
<th>Centrifugal Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>P-500</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Function**: To increase the pressure of the stream fed to the membrane.

**Operation**: Continuous

**Type**: Pump

<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>

- **Flow Rate (lb/hr)**: 282388 282388
- **Inlet Temperature (°F)**: 103 106
- **Pressure (psia)**: 225 575

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

**Cost of utilities/year:**
- **Electricity**: $141,000.00

**Purchase Cost**: $13,300.00

**Bare Module Cost**: $44,000.00

**Total Bare Module Cost**: $44,000.00

**Comments**: 

---

**Pumps**

---

76
**HEAT EXCHANGER**

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

**Function**: Heats feed to the reformer using oxyreactor products

**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>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>

| Flow Rate (lb/hr) | 824709 | 806901 |
| Inlet Temperature (°F) | 1211 | 279 |
| Outlet Temperature (°F) | 353 | 1094 |

**Design Data:**
- Surface area (ft²): 21000
- LMTD (°F): 141
- Heat duty (MMBTU/hr): 442.436
- Construction materials: Stainless steel/stainless steel

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

**Comments**: Costed by combining a 12000sqft and 9000sqft 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></td>
<td>HX-201</td>
</tr>
<tr>
<td>No. Required</td>
<td></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**:  
- Surface area ($ft^2$) | 11000  
- Cooling Duty (MMBTU/hr) | 550  
- Construction materials | Carbon Steel

**Cost of utilities/year:**  
- Cooling Water | $2,799,524.00

**Purchase Cost:**  
- $230,000.00

**Total Bare Module Cost:**  
- $738,300.00
## HEAT EXCHANGER

<table>
<thead>
<tr>
<th>Identification</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>Heat exchanger</td>
<td></td>
</tr>
<tr>
<td>Item No.</td>
<td>HX-500</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Function**: To increase the temperature of the stream fed to the membrane.

**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>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)**
- Tube Side: 282388
- Shell Side: 177101

**Inlet Temperature (°F)**
- Tube Side: 106
- Shell Side: 338

**Outlet Temperature (°F)**
- Tube Side: 162
- Shell Side: 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**:  

# Heaters

<table>
<thead>
<tr>
<th>Identification</th>
<th>Item</th>
<th>Heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td></td>
<td>H-101</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**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>

<table>
<thead>
<tr>
<th>Flow Rate (lb/hr)</th>
<th>282388</th>
<th>282388</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°F)</td>
<td>162</td>
<td>257</td>
</tr>
<tr>
<td>Pressure (psia)</td>
<td>575</td>
<td>575</td>
</tr>
</tbody>
</table>

**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

**Identification**  
Item: Heat exchanger  
Item No.: H-501  
No. Required: 1

**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>S-509</td>
<td>S-510</td>
<td></td>
</tr>
</tbody>
</table>

### Design Data:

- **Flow Rate (lb/hr):**
  - S-509: 177101
  - S-510: 177101

- **Temperature (°F):**
  - S-509: 113
  - S-510: 100

- **Pressure (psia):**
  - S-509: 250
  - S-510: 250

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

**Construction materials**

### Cost of utilities/year:

- **Cooling Water:** $130,000.00
- **Construction materials:** Carbon Steel

**Purchase Cost:** $56,000.00

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

**Comments:**

---

**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>S-509</td>
<td>S-510</td>
<td></td>
</tr>
</tbody>
</table>

### Design Data:

- **Flow Rate (lb/hr):**
  - S-509: 177101
  - S-510: 177101

- **Temperature (°F):**
  - S-509: 113
  - S-510: 100

- **Pressure (psia):**
  - S-509: 250
  - S-510: 250

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

**Construction materials**

### Cost of utilities/year:

- **Cooling Water:** $130,000.00
- **Construction materials:** Carbon Steel

**Purchase Cost:** $56,000.00

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

**Comments:**
## 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-502</td>
</tr>
<tr>
<td>No. Required</td>
<td></td>
<td>1</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

### Cost of utilities/year:
- Natural gas: $164,000.00
- Construction materials: Carbon Steel

### Purchase Cost:
- $332,000.00

### Bare Module Cost:
- $727,000.00

### Comments:
### Reactors

#### REFORMER

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

**Function**: Produces propene through propane dehydrogenation

**Operation**: Continuous

**Type**: N/A

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

| Temperature (°F) | 1094 | 1094 |
| Pressure (psi)   | 73   | 56.3 |
| Flow rate (lb/hr)| 806901 | 806901 |

**Composition (lb/hr)**

- **Propylene**
  - Inlet: 406720
  - Outlet: 278858
- **Propylene**
  - Inlet: 13936
  - Outlet: 135420
- **Hydrogen**
  - Inlet: 0
  - Outlet: 5812
- **Oxygen**
  - Inlet: 0
  - Outlet: 0
- **Water**
  - Inlet: 386235
  - Outlet: 386235
- **Carbon monoxide**
  - Inlet: 0.01
  - Outlet: 0.01
- **Carbon dioxide**
  - Inlet: 2.25
  - Outlet: 2.25
- **Methane**
  - Inlet: 0.03
  - Outlet: 203
- **Ethane**
  - Inlet: 5.56
  - Outlet: 120
- **Ethene**
  - Inlet: 1.76
  - Outlet: 250

**Design Data**

- Number of tubes: 326
- Catalyst: 2.6%Pt-Sn/ZnAl2O4
- Propane conversion: 0.32
- Propylene selectivity: 0.976
- C1-C2 selectivity: 0.024
- COx selectivity: 0
- Diameter (in): 1.8
- Vessel weight (lb): 2,649,700
- Particle diameter (in): 0.1
- Velocity (ft/s): 32
- Bulk density (g/cm³): 0.336
- WHSV (1/hr): 2
- Catalyst weight (lb): 67655
- Regeneration time (hr): 1
- Void fraction: 0.7
- Duty (MMBTU/hr): 53.99
- Construction material: Stainless Steel 304

**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</th>
<th>No. Required</th>
<th>Vertical Vessel</th>
<th>R-102</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Produces propene through propane oxydehydrogenation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation</td>
<td>Continuous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Cost of utilities/year:</th>
<th>$</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase Cost:</td>
<td>$</td>
<td>154,000.00</td>
</tr>
<tr>
<td>Bare Module Cost:</td>
<td>$</td>
<td>638,000.00</td>
</tr>
<tr>
<td>Associated Costs:</td>
<td>Catalyst</td>
<td>$</td>
</tr>
<tr>
<td>Total Bare Module Cost:</td>
<td>$</td>
<td>5,621,000.00</td>
</tr>
</tbody>
</table>

Comments: R-104, R-106, R-108 are identical to R-102
<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item</th>
<th>Item No.</th>
<th>Function:</th>
<th>Operation:</th>
<th>Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M-500</td>
<td>To provide an final separation of propene from propane.</td>
<td>Continuous</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<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     |
| Composition (lb/hr) |  |  |  |
| Propane           | 90036  | 928    | 89108  |
| Propene           | 4592   | 176174 | 16207  |

| Design Data: | Selectivity (propylene/propane) | 35 |
|             | Propene permeance (mol/m²/Pa)   | 2.77E-08 |
|             | Area (ft²)                      | 281692  |
|             | Pressure drop: feed to permeate | 555    |
|             | Pressure drop: feed to retentate | 555    |

| 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>Reactor Complex</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>
<td>1</td>
<td>$74,400,000.00$</td>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$519,971,000.00$</td>
</tr>
<tr>
<td>Water Adsorption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-201</td>
<td>$795,000.00$</td>
<td>1.8</td>
<td>$0.00$</td>
<td>$1,431,000.00$</td>
<td>1</td>
<td>$1,431,000.00$</td>
</tr>
<tr>
<td>HX-201</td>
<td>$300,000.00$</td>
<td>3.21</td>
<td>$0.00$</td>
<td>$963,000.00$</td>
<td>1</td>
<td>$963,000.00$</td>
</tr>
<tr>
<td>AD-201</td>
<td>$209,000.00$</td>
<td>4.16</td>
<td>$2,042,000.00$</td>
<td>$869,000.00$</td>
<td>2</td>
<td>$3,780,000.00$</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$6,174,000.00$</td>
</tr>
<tr>
<td>CO2 Absorption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AB-201</td>
<td></td>
<td></td>
<td>$3,170,000.00$</td>
<td>$3,170,000.00$</td>
<td>1</td>
<td>$3,170,000.00$</td>
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<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$3,170,000.00$</td>
</tr>
<tr>
<td>Distillation Column</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-201</td>
<td>$3,100,000.00$</td>
<td>2.3</td>
<td>$0.00$</td>
<td>$7,130,000.00$</td>
<td>1</td>
<td>$7,130,000.00$</td>
</tr>
<tr>
<td>C-202</td>
<td>$3,700,000.00$</td>
<td>2.3</td>
<td>$0.00$</td>
<td>$8,510,000.00$</td>
<td>1</td>
<td>$8,510,000.00$</td>
</tr>
<tr>
<td>DC-202</td>
<td>$1,460,000.00$</td>
<td>4.16</td>
<td>$3,933,000.00$</td>
<td>$6,000,000.00$</td>
<td>1</td>
<td>$9,933,000.00$</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$25,573,000.00$</td>
</tr>
<tr>
<td>Hybrid C3 Splitter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC-500</td>
<td>$13,050,000.00$</td>
<td>3.84</td>
<td>$3,066,000.00$</td>
<td>$50,115,000.00$</td>
<td>1</td>
<td>$53,181,000.00$</td>
</tr>
<tr>
<td>P-500</td>
<td>$13,300.00$</td>
<td>3.31</td>
<td>$0.00$</td>
<td>$44,000.00$</td>
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<td>$44,000.00$</td>
</tr>
<tr>
<td>HX-500</td>
<td>$52,000.00$</td>
<td>3.17</td>
<td>$0.00$</td>
<td>$164,000.00$</td>
<td>1</td>
<td>$164,000.00$</td>
</tr>
<tr>
<td>H-500</td>
<td>$847,000.00$</td>
<td>3.17</td>
<td>$0.00$</td>
<td>$1,932,000.00$</td>
<td>1</td>
<td>$1,932,000.00$</td>
</tr>
<tr>
<td>M-500</td>
<td>$29,666,000.00$</td>
<td>1.86</td>
<td>$1,206,000.00$</td>
<td>$55,178,000.00$</td>
<td>1</td>
<td>$56,384,000.00$</td>
</tr>
<tr>
<td>C-500</td>
<td>$2,442,000.00$</td>
<td>2.15</td>
<td>$0.00$</td>
<td>$5,251,000.00$</td>
<td>1</td>
<td>$5,251,000.00$</td>
</tr>
<tr>
<td>H-501</td>
<td>$56,000.00$</td>
<td>3.17</td>
<td>$0.00$</td>
<td>$178,000.00$</td>
<td>1</td>
<td>$178,000.00$</td>
</tr>
<tr>
<td>H-502</td>
<td>$332,000.00$</td>
<td>3.17</td>
<td>$0.00$</td>
<td>$727,000.00$</td>
<td>1</td>
<td>$727,000.00$</td>
</tr>
<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>
</tr>
<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></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operations</strong></td>
<td></td>
</tr>
<tr>
<td>Operators per Shift:</td>
<td>1</td>
</tr>
<tr>
<td>(assuming 5 shifts)</td>
<td></td>
</tr>
<tr>
<td>Direct Wages and Benefits:</td>
<td>$40</td>
</tr>
<tr>
<td>(operator hour)</td>
<td></td>
</tr>
<tr>
<td>Direct Salaries and Benefits</td>
<td>15%</td>
</tr>
<tr>
<td>Operating Supplies and Services:</td>
<td>5%</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%</td>
</tr>
<tr>
<td>Employee Relations Department:</td>
<td>5.00%</td>
</tr>
<tr>
<td>Business Services:</td>
<td>7.42% 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>
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.
### Variable Cost Summary

**Variable Costs at 100% Capacity:**

<table>
<thead>
<tr>
<th>General Expenses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Selling / Transfer Expenses:</td>
<td>$15,276,514</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>$6,396,047</td>
</tr>
</tbody>
</table>

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

| Raw Materials                           | $0.174126 per lb of Propene | $206,725,912 |
| Byproducts                              | $0.000000 per lb of Properie | $0  |
| Utilities                               | $0.050153 per lb of Propene | $77,399,839 |

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

### Fixed Cost Summary

**Operations**

| Direct Wages and Benefits                | $416,000 |
| Direct Salaries and Benefits            | $62,400  |
| Operating Supplies and Services         | $24,960  |
| Technical Assistance to Manufacturing   | $300,000 |
| Control Laboratory                      | $325,000 |

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

**Maintenance**

| Wages and Benefits                      | $39,756,403 |
| Salaries and Benefits                   | $9,910,101  |
| Materials and Services                  | $39,756,403 |
| Maintenance Overhead                    | $1,977,820  |

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

**Operating Overhead**

| General Plant Overhead:                 | $3,562,347 |
| Mechanical Department Services:        | $1,224,174 |
| Employee Relations Department:         | $2,980,260 |
| Business Services:                     | $3,712,969 |

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

**Property Taxes and Insurance**

| Property Taxes and Insurance:           | $17,669,512 |

**Other Annual Expenses**

| Rental Fees (Office and Laboratory Space): | $ - |
| Licensing Fees:                           | $ - |
| Miscellaneous:                           | $ - |

**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:** $80,643,770

## 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:** $83,475,613

## Total Permanent Investment

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Land</td>
<td>$17,669,512</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:** $989,492,647

**Site Factor:** 100

**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>$16,571,886</td>
<td>$8,285,943</td>
<td>$8,285,943</td>
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</tbody>
</table>

**Present Value at 8%**

<table>
<thead>
<tr>
<th>Item</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounts Receivable</td>
<td>$15,344,339</td>
<td>$7,103,611</td>
<td>$5,777,649</td>
</tr>
<tr>
<td>Cash Reserves</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Accounts Payable</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propene Inventory</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td>$1,618,518,516</td>
<td>$1,618,518,516</td>
<td>$1,618,518,516</td>
</tr>
</tbody>
</table>
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 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 feedstocks 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 nontoxic 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

General Information

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

This Process will Yield

- 194,883 lb of Propene per hour
- 4,677,186 lb of Propene per day
- 1,543,284,240 lb of Propene per year

Price

$0.33 /lb

Chronology

<table>
<thead>
<tr>
<th>Year</th>
<th>Action</th>
<th>Distribution of Permanent Investment</th>
<th>Production Capacity</th>
<th>Depreciation 5 year NACRS</th>
<th>Product Price</th>
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<tr>
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<td>Design</td>
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<td>Construction</td>
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<tr>
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<tr>
<td>2022</td>
<td>Production</td>
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<tr>
<td>2-6% P+-Sn/ZnAl2O6</td>
<td>Catalysts</td>
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</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>$0.134 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

| Byproduct | Unit | Ratio to Product | Byproduct Selling Price |

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>5.48E-10 unit per lb of Propene</td>
<td>$1330000.000 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
### Variable Costs

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

#### Working Capital

<table>
<thead>
<tr>
<th>Category</th>
<th>Days</th>
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<tbody>
<tr>
<td>Accounts Receivable</td>
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<tr>
<td>Cash Reserves (excluding Raw Materials)</td>
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<tr>
<td>Accounts Payable</td>
<td>30</td>
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<tr>
<td>Propene Inventory</td>
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<tr>
<td>Raw Materials</td>
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</tbody>
</table>

#### Total Permanent Investment

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

#### Fixed Costs

**Operations**
- Operators per Shift: 1 (assuming 5 shifts)
- Direct Wages and Benefits: $40 /operator hour
- Direct Salaries and Benefits: 15% of Direct Wages and Benefits
- Operating Supplies and Services: 6% of Direct Wages and Benefits
- Technical Assistance to Manufacturing: $50,000.00 per year, for each Operator per Shift
- Control Laboratory: $55,000.00 per year, for each Operator per Shift

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

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

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

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

**Other Annual Expenses**
- Rental Fees (Office and Laboratory Space): $0
- Licensing Fees: $0
- Miscellaneous: $0

**Depletion Allowance**
- Annual Depletion Allowance: $0
<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage of Design Capacity</th>
<th>Product Unit Price</th>
<th>Sales</th>
<th>Gross Costs</th>
<th>Working Costs</th>
<th>Year Costs</th>
<th>Fixed Costs</th>
<th>Depreciation</th>
<th>Amortization</th>
<th>Taxes</th>
<th>Net Income</th>
<th>Cash Flow</th>
<th>Cumulative Net Present Value at 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
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<td>$0.33</td>
<td>$229,177.70</td>
<td>-</td>
<td>(8,285,000)</td>
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<td>-</td>
<td>(1,005,046,000)</td>
</tr>
<tr>
<td>2017</td>
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<td>(212,236,000)</td>
<td>(121,877,300)</td>
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<td>-</td>
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<tr>
<td>2018</td>
<td>20%</td>
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<td>(212,236,000)</td>
<td>(121,877,300)</td>
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<td>(212,236,000)</td>
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<td>-</td>
<td>-</td>
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<tr>
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<td>(212,236,000)</td>
<td>(121,877,300)</td>
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<td>-</td>
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<td>-</td>
<td>(1,005,046,000)</td>
</tr>
<tr>
<td>2023</td>
<td>70%</td>
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<td>(8,285,000)</td>
<td>(212,236,000)</td>
<td>(121,877,300)</td>
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<td>-</td>
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<td>80%</td>
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<tr>
<td>2025</td>
<td>90%</td>
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<td>$1,274,500.40</td>
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<td>(8,285,000)</td>
<td>(212,236,000)</td>
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<td>2026</td>
<td>100%</td>
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<td>(212,236,000)</td>
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<td>-</td>
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<td>-</td>
<td>(1,005,046,000)</td>
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</table>

Cash Flow Summary
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 is shown below in Figure 8.

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<tbody>
<tr>
<td>Annual Sales</td>
<td>458,355,419</td>
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<td>Annual Costs</td>
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<tr>
<td>Depreciation</td>
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<td>Income Tax</td>
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<tr>
<td>Net Earnings</td>
<td>(67,368,716)</td>
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<td>Total Capital Investment</td>
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<td>ROI</td>
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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 8: Expected IRR as a function of Fixed Costs, Variable Costs, and Total Permanent Investment

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<th>$576,554,248</th>
<th>$648,710,418</th>
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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

\[ m_{\text{catalyst}} = \text{catalyst loading weight (lb)} \]
\[ m_{\text{propane}} = \text{propane feed flowrate (lb/hr)} \]
\[ WHSV = \text{weighted hourly space velocity (hr}^{-1}) \]
\[ V_R = \text{reactor volume (ft}^3) \]
\[ \rho_{\text{bulk}} = \text{bulk density of packed bed (lb/ft}^3) \]
\[ \rho_{\text{particle}} = \text{density of catalyst particle (lb/ft}^3) \]
\[ \varepsilon = \text{void fraction} \]
\[ \tau = \text{residence time (hr)} \]
\[ Q = \text{Volumetric flowrate (ft}^3/\text{hr}) \]
\[ D_i = \text{inner tube diameter (ft)} \]
\[ k = \text{thermal conductivity of packed bed (Btu/hr}*^0 \text{F}*ft) \]
\[ h = \text{convective heat transfer of air (Btu/hr}*^0 \text{F}*ft}^2) \]
\[ Bi = \text{Biot number, Bi < 0.1 for zero temperature gradient} \]
\[ L = \text{tube length (ft)} \]
\[ N = \text{number of tubes} \]
\[ t_{sp} = \text{wall thickness (ft)} \]
\[ P_d = \text{design pressure (psia)} \]
\[ S = \text{maximum allowable stress of shell material (psia)} \]
\[ E = \text{fractional weld efficiency} \]
\[ \rho_m = \text{material density (lb/ft}^3) \]
\[ W = \text{vessel weight (lb)} \]
\[ \nu_s = \text{superficial velocity (ft/s)} \]
\[ D_p = \text{particle diameter (in)} \]
\[ \phi = \text{thiele modulus} \]
\[ r = \text{reaction rate (psia/s)} \]
\[ D_c = \text{diffusion rate (psia/s)} \]
\[ \Delta p = \text{pressure drop (psia/s)} \]
\[ \mu = \text{dynamic viscosity of fluid (lb/ft}*\text{hr}) \]
\[ \rho_f = \text{density of fluid} \left( \frac{lb}{ft^3} \right) \]

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

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

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

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

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

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

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

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

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

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

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

**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 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 flowrate 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**

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

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

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

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

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

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

\[F_f = \text{Feed Flow} \]
\[F_p = \text{Permeate flow} \]
\[F_r = \text{Retentate flow} \]
\[ Y_a = \text{Permeate Propylene comp} \]
\[ X_a = \text{Retentate Propylene comp} \]
\[ Z_a = \text{Feed Propylene comp} \]
\[ P_p = \text{Permeate pressure} \]
\[ P_r = \text{Retentate Pressure} \]
\[ P_f = \text{Feed Pressure} \]
\[ S = \text{Selectivity} \]
\[ \text{PermA} = \text{Permeability propylene} \]
\[ \text{PermB} = \text{Permeability propane} \]

**Pump Calculations**

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

- \( W \) = work (HP)
- \( F \) = volumetric flowrate (ft\(^3\)/hr)
- \( \Delta P \) = pressure change (psia)

\[ H = \frac{\Delta P}{\rho_L} \]

- \( H \) = head (ft)
- \( \rho_L \) = liquid’s density (lb/ft\(^3\))

**Heat Exchanger Calculations**

\[ Q = U A \Delta T_{LM} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln \left( \frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}} \right)} \]

- \( Q \) = duty of the exchanger (BTU/hr)
- \( U \) = heat exchanger transfer coefficient (BTU/hr/ft/F)
- \( A \) = Surface area of the exchanger (ft\(^2\))
- \( T_{hi} \) = inlet temperature of hot stream (R)
- \( T_{ho} \) = outlet temperature of hot stream (R)
- \( T_{ci} \) = inlet temperature of cold stream (R)
- \( T_{co} \) = outlet temperature of cold stream (R)

**Reflux Accumulator Calculations**

\[ F = (1 + R) \times (D_{volumetric}) \]

\[ \text{Volume} = 2 \times F \times \tau \]

Assume L/D=2

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

- \( F \) = volumetric flow rate (ft\(^3\)/hr)
- \( D_{volumetric} \) = distillate flow rate (ft\(^3\)/hr)
- \( R \) = reflux ratio
- \( L \) = length of drum (ft)
- \( D \) = diameter of drum (ft)
- \( \tau \) = residence time (hr)
Distillation Column Calculations

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

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

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

\[ U = 0.85 \times U_f \]

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

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

\( U_f \) = flooding velocity (ft/s)
\( C_{SB} \) = flooding correlation
\( F_{ST} \) = surface tension
\( \sigma \) = surface tension of liquid (dyne/cm)
\( F_T \) = 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=C2 / 
HYDROGEN H2 / 
OXYGEN O2 / 
WATER H20 / 
CO CO / 
CO2 CO2 / 
METHANE CH4 / 
ETHANE C2H6 / 
ETHENE C2H4
SOLVE
RUN-MODE MODE=SIM
FLOWSHEET
BLOCK M101 IN=s110 s105 OUT=s111 s15
BLOCK M102 IN=s104 s103 s114 OUT=s105
BLOCK C201 IN=s206 OUT=s207
BLOCK C202 IN=s205 OUT=s206
BLOCK AE201 IN=s114 OUT=s203 s202
BLOCK MEA201 IN=s203 OUT=s204 s205
BLOCK DC201 IN=s207 OUT=s301
BLOCK H101 IN=s112 OUT=s114 s1
BLOCK T101 IN=s111 OUT=s112
BLOCK H302 IN=s315 OUT=s316
BLOCK HX301 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
APD8F9.txt

BLOCK P101 IN=2 OUT=S116
BLOCK R101 IN=S15 OUT=S108
BLOCK R102 IN=S108 S109 OUT=1 S2
BLOCK B5 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 PREHFLMX 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 .0124797561 / &
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 9.232328070 / 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 9.232328070 / ETHENE &
21.54209882

STREAM S112
SUBSTREAM MIXED TEMP=457.3765616 PRES=34.80905705
MOLE-FLOW PROPANE 2390.492724 / PROPENE 2449.013269 / &
STREAM S114
SUBSTREAM MIXED TEMP=176.00000000 PRES=34.80905705
MOLE-FLOW PROPANE 7515.089963 / PROPENE 11378.34025 / &
HYDROGEN 2993.952830 / WATER 14411.37866 / CO &
68.20321581 / CO2 46.09549429 / METHANE 43.66554116 / &
ETHANE 14.35664435 / ETHENE 31.13185524

STREAM S116
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW PROPANE 365.9795997 / PROPENE 111.8183337 / &
HYDROGEN 6.746443619 / OXYGEN 1.697640051 / WATER &
9361.705520 / CO 1.411510488 / CO2 1.651896446 / &
METHANE .2052380544 / ETHANE .3803234697 / ETHENE &
.5618458726

STREAM S202
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW WATER 77.35835349 / CO 43.74710756 / CO2 &
42.10509626 / METHANE .2672388536 / ETHANE .0769796357 / &
ETHENE 18.28749062

STREAM S203
SUBSTREAM MIXED TEMP=80.00000000 PRES=34.80905705
MOLE-FLOW PROPANE 2024.512890 / PROPENE 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 / PROPENE 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 / PROPENE 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 / PROPENE 2137.196845 / &
HYDROGEN 1508.369993 / OXYGEN 39.33135582 / WATER &
2.890759340 / METHANE 26.45516083 / ETHANE 7.620983704

STREAM S301
SUBSTREAM MIXED TEMP=112.3483327 PRES=241.98000000
MOLE-FLOW PROPANE 2010.661171 / PROPENE 1744.186738 / &
HYDROGEN 5.94247871E-6 / OXYGEN 1.74824656E+4 / WATER &
2.890759340 / METHANE 7.26307830E-4 / ETHANE &
.0686083146

STREAM S303
SUBSTREAM MIXED TEMP=106.2000000 PRES=225.00000000
MOL-E-FLOW PROPANE 1898.027354 / PROPENE 1744.174259 / &
HYDROGEN 5.94247871E-6 / OXYGEN 1.74824656E-4 / &
METHANE 7.26307830E-4 / ETHANE .0688081146

STREAM S304
SUBSTREAM MIXED TEMP=108.8871559 PRES=521.0000000
MOL-E-FLOW PROPANE 1898.027354 / PROPENE 1744.174259 / &
HYDROGEN 5.94247871E-6 / OXYGEN 1.74824656E-4 / &
METHANE 7.26307830E-4 / ETHANE .0688081146

STREAM S305
SUBSTREAM MIXED TEMP=115.5200000 PRES=521.0000000
MOL-E-FLOW PROPANE 1898.027354 / PROPENE 1744.174259 / &
HYDROGEN 5.94247871E-6 / OXYGEN 1.74824656E-4 / &
METHANE 7.26307830E-4 / ETHANE .0688081146

STREAM S306
SUBSTREAM MIXED TEMP=179.0000000 PRES=521.0000000
MOL-E-FLOW PROPANE 1898.027354 / PROPENE 1744.174259 / &
HYDROGEN 5.94247871E-6 / OXYGEN 1.74824656E-4 / &
METHANE 7.26307830E-4 / ETHANE .0688081146

STREAM S307
SUBSTREAM MIXED TEMP=179.0000000 PRES=521.0000000
MOL-E-FLOW PROPANE 13.61769511 / PROPENE 1744.192306 / &
HYDROGEN 5.94265287E-6 / OXYGEN 1.74824171E-4 / &
METHANE 7.26327165E-4 / ETHANE .0688098111

STREAM S308
SUBSTREAM MIXED TEMP=26.20599800 PRES=20.00000000
MOL-E-FLOW PROPANE 13.61769511 / PROPENE 1744.192306 / &
HYDROGEN 5.94265287E-6 / OXYGEN 1.74824171E-4 / &
METHANE 7.26327165E-4 / ETHANE .0688098111

STREAM S309
SUBSTREAM MIXED TEMP=262.6361348 PRES=250.00000000
MOL-E-FLOW PROPANE 13.61769511 / PROPENE 1744.192306 / &
HYDROGEN 5.94265287E-6 / OXYGEN 1.74824171E-4 / &
METHANE 7.26327165E-4 / ETHANE .0688098111

STREAM S315
SUBSTREAM MIXED TEMP=232.6643240 PRES=250.00000000
MOL-E-FLOW PROPANE 13.61769511 / PROPENE 1744.192306 / &
HYDROGEN 5.94265287E-6 / OXYGEN 1.74824171E-4 / &
METHANE 7.26327165E-4 / ETHANE .0688098111

STREAM S316
SUBSTREAM MIXED TEMP=100.00000000 PRES=250.00000000
MASS-FLOW PROPANE 13.61769511 / PROPENE 1744.192306 / &
HYDROGEN 5.94265287E-6 / OXYGEN 1.74824171E-4 / &
METHANE 7.26327165E-4 / ETHANE .0688098111

DEF-STREAMS HEAT S2
DEF-STREAMS HEAT S8
DEF-STREAMS HEAT S9
DEF-STREAMS HEAT S10
DEF-STREAMS HEAT S11
DEF-STREAMS HEAT S12

Page 4
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 FSPLIT FRAC RECY 0.9
BLOCK B3 FSPLIT
   DUTY S10 530066618.9 / S11 220341562. / S12 54314968. / &
   S13 11345144.9 / S14 161962246.
BLOCK SP101 FSPLIT FRAC S3 0.1
BLOCK AD201 SEP PARAM
   FRAC STREAM=S202 SUBSTREAM=MIXED COMPS=PROPANE PROPENE &
   HYDROGEN OXYGEN WATER CO CO2 METHANE ETHANE ETHENE &
   FRACS=0. 0. 0. 0. 0.95 0. 0. 0.01 0.01 0.
BLOCK M301 SEP PARAM
   MOLE-FLOW STREAM=S307 SUBSTREAM=MIXED COMPS=PROPANE &
   PROPENE FLOWS=21.03801465 4186.578359
BLOCK MEA201 SEP PARAM
   FRAC STREAM=S204 SUBSTREAM=MIXED COMPS=PROPANE PROPENE &
   HYDROGEN OXYGEN WATER CO CO2 METHANE ETHANE ETHENE &
   FRACS=0. 0. 0.001 0. 0.29 0. 0.94 0. 0. 0.
BLOCK H000 HEATER PARAM PRES=52.5 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=34.80905705 DPPARMOPT=NO
   BLOCK=OPTION FREE-WATER=YES
BLOCK H301 HEATER PARAM TEMP=257.0000000 PRES=575.0000000 DPPARMOPT=NO
BLOCK H302 HEATER PARAM TEMP=100.0000000 PRES=250.0000000 DPPARMOPT=NO
BLOCK H303 HEATER
PARAM TEMP=71.60000000 PRES=20.00000000 DPPARMOPT=NO

BLOCK HX101 HEATX
PARAM T-COLD=1094. PRES-HOT=52.500000000 MIN-TAPP=18.000000000
FEEDS HOT=s110 COLD=s105
OUTLETS HOT s111 COLD=s106
HOT-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
COLD-SIDE DPPARMOPT=NO
TQ-PARAM CURVE=YES

BLOCK HX301 HEATX
PARAM DUTY=1000000. CALC-TYPE=DESIGN MIN-TAPP=7.000000000 &
U-OPTION=PHASE P-OPTION=CONSTANT CALC-METHOD=SHORTCUT
FEEDS HOT=s309 COLD=s304
OUTLETS HOT s315 COLD=s305
HOT-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
COLD-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
TQ-PARAM CURVE=YES

BLOCK DC201 RADFRAC
PARAM NSTAGE=20 ALGORITHM=STANDARD MAXOL=100 DAMPING=NONE
COL-CONFIG CONDENSOR=PARTIAL=V
FEEDS s207 19
PRODUCTS s301 20 L / 3 1 V
P-SPEC 1 270.0000000
COL-SPECS DP-STAGE=.1100000000 MOLE-D=3472.280629 MOL-RR=4.5 &
DP-COND=10.000000000
TRAY-SIZE 1 2 19 FLEXI NPASS=4

BLOCK DC301 RADFRAC
PARAM NSTAGE=90 ALGORITHM=STANDARD MAXOL=25 DAMPING=NONE
COL-CONFIG CONDENSOR=TOTAL
FEEDS s301 45
PRODUCTS s303 1 L / s302 90 L
P-SPEC 1 225.0000000
COL-SPECS DP-STAGE=.1100000000 MOLE-D=6613.867866 MOL-RR=5. &
DP-COND=10.000000000
TRAY-SIZE 1 2 89 FLEXI NPASS=4

BLOCK B2 RSTOIC
PARAM TEMP=1094. PRES=14.7 COMBUSTION=YES PROD-NOX=NO

BLOCK R101 RSTOIC
PARAM TEMP=1094.0000000 PRES=73.000000000 SERIES=YES
STOIC 1 MIXED PROPANE -1. / PROPENE 1. / HYDROGEN 1.
STOIC 2 MIXED PROPANE -1. / METHANE 1. / ETHENE 1.
STOIC 3 MIXED ETHENE -1. / HYDROGEN -1. / ETHANE 1.
CONV 1 MIXED PROPANE 0.313
CONV 2 MIXED PROPANE 0.002
CONV 3 MIXED ETHENE 0.3

BLOCK R102 RSTOIC
PARAM TEMP=1094.0000000 PRES=56.300000000 SERIES=YES
STOIC 1 MIXED PROPANE -1. / PROPENE 1. / HYDROGEN 1.
STOIC 2 MIXED PROPANE -1. / ETHENE 1. / METHANE 1.
STOIC 3 MIXED PROPANE -1. / OXYGEN -5. / CO2 3. / &
WATER 4.
STOIC 4 MIXED PROPANE -1. / OXYGEN -3.5 / CO 3. / &
WATER 4.
STOIC 5 MIXED ETHENE -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=100.0000000 SB-MAXIT=30 & SB-TOL=0.0001

BLOCK C202 COMPR
PARAM TYPE=ISENTROPIC PRES=300.0000000 SB-MAXIT=30 & SB-TOL=0.0001

BLOCK C301 COMPR
PARAM TYPE=ISENTROPIC PRES=20.0000000 NPHASE=2 SB-MAXIT=30 & SB-TOL=0.0001 MODEL-TYPE=TURBINE BLOCK-OPTION FREE-WATER=NO

BLOCK C302 COMPR
PARAM TYPE=ISENTROPIC PRES=20.0000000 NPHASE=2 SB-MAXIT=30 & SB-TOL=0.0001 MODEL-TYPE=TURBINE BLOCK-OPTION FREE-WATER=NO

BLOCK C303 COMPR
PARAM TYPE=ISENTROPIC PRES=250.0000000 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

STREAM-REPORT
MOLEFLOW MASSFLOW PROPERTIES=PS 1 INCL-STREAMS=S101 & S102 S103 S104 S105 S108 S110 S111 S112 S114 & S116 S114

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=SLTIP PHASE=V CBASIS=PARTIALPRES & RBASIS=CAT-WT PRES-UNIT="BAR"
-APD8F9.txt

REAC-DATA 5 NAME=HYDROG REAC-CLASS=POWERLAW STATUS=ON
RATE-CON 1 PRE-EXP=0.015 ACT-ENERGY=25795.35684
RATE-CON 3 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 / 5

............

Page 8
**Block Report**

---

```plaintext
~AP6AG0.tmp

**BLOCK:** AD201  **MODEL:** SEP

<table>
<thead>
<tr>
<th>INLET STREAM:</th>
<th>OUTLET STREAMS:</th>
<th>PROPERTY OPTION SET:</th>
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<tbody>
<tr>
<td>S114</td>
<td>S203 S202</td>
<td>UNIQUAC UNIQUAC / IDEAL GAS</td>
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*** MASS AND ENERGY BALANCE ***

<table>
<thead>
<tr>
<th><strong>TOTAL BALANCE</strong></th>
<th><strong>IN</strong></th>
<th><strong>OUT</strong></th>
<th><strong>RELATIVE DIFF.</strong></th>
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<tbody>
<tr>
<td>MOLE(LBMOL/HR)</td>
<td>13621.6</td>
<td>13621.6</td>
<td>-0.53417E-15</td>
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<tr>
<td>MASS(LB/HR)</td>
<td>433918.</td>
<td>433918.</td>
<td>-0.53657E-15</td>
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<tr>
<td>ENTHALPY(BTU/HR)</td>
<td>-0.244816E+09</td>
<td>-0.235166E+09</td>
<td>0.40569E-01</td>
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*** CO2 EQUIVALENT SUMMARY ***

<table>
<thead>
<tr>
<th><strong>FEED STREAMS CO2</strong></th>
<th><strong>PRODUCT STREAMS CO2</strong></th>
<th><strong>NET STREAMS CO2 PRODUCTION</strong></th>
<th><strong>UTILITIES CO2 PRODUCTION</strong></th>
<th><strong>TOTAL CO2 PRODUCTION</strong></th>
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<tbody>
<tr>
<td>0.000000</td>
<td>12430.4</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
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*** INPUT DATA ***

**FLASH SPECS FOR STREAM S203**

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<th>TWO PHASE TP FLASH</th>
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<tbody>
<tr>
<td>PRESSURE DROP PSI</td>
</tr>
<tr>
<td>MAXIMUM NO. ITERATIONS</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
</tr>
</tbody>
</table>

**FLASH SPECS FOR STREAM S202**

<table>
<thead>
<tr>
<th>TWO PHASE TP FLASH</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESSURE DROP PSI</td>
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<tr>
<td>MAXIMUM NO. ITERATIONS</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
</tr>
</tbody>
</table>

**FRACTION OF FEED**

<table>
<thead>
<tr>
<th>SUBSTREAM= MIXED</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREAM= S202 CPT= PROPANE FRACTION= 0.0</td>
</tr>
<tr>
<td>PROPANE 0.0</td>
</tr>
<tr>
<td>HYDROGEN 0.0</td>
</tr>
<tr>
<td>OXYGEN 0.0</td>
</tr>
<tr>
<td>WATER 0.950000</td>
</tr>
<tr>
<td>CO 0.0</td>
</tr>
<tr>
<td>CO2 0.0</td>
</tr>
<tr>
<td>METHANE 0.010000</td>
</tr>
<tr>
<td>ETHANE 0.010000</td>
</tr>
<tr>
<td>ETHENE 0.0</td>
</tr>
</tbody>
</table>

*** RESULTS ***

| COMPONENT = PROPANE |
| STREAM S203 MIXED | SPLIT FRACTION 1.00000 |

| COMPONENT = PROPANE |
| STREAM S203 MIXED | SPLIT FRACTION 1.00000 |

<table>
<thead>
<tr>
<th>COMPONENT = HYDROGEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Page 1</td>
</tr>
</tbody>
</table>
```

---

129
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 ***

TOTAL BALANCE
IN  OUT  RELATIVE DIFF.
MOL (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 CO2E PRODUCTION  0.00000  LB/HR

*** INPUT DATA ***

FRACTION OF FLOW  STRM=RECY  FRAC=  0.90000

*** RESULTS ***

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

BLOCK: B2  MODEL: RSTOIC
-------------------------------------------------
INLET STREAMS:  3
OUTLET STREAM:  S6  PURGE  S7

Page 2
OUTLET HEAT STREAM: S8
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

IN OUT GENERATION RELATIVE DIFF.

TOTAL BALANCE
MOLE (LB/MOL/HR) 10996.3 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 CO2 PRODUCTION 73555.9 LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE F 1,094.00
SPECIFIED PRESSURE PSIA 14.7000
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.00010000
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 -0.774441E+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 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/MOL/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>483.58</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>90.471</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>3318.8</td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>58.370</td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>17.892</td>
<td></td>
</tr>
<tr>
<td>C6</td>
<td>8.0303</td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td>9.9568</td>
<td></td>
</tr>
</tbody>
</table>

Page 3
V-L PHASE EQUILIBRIUM:

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(T)</th>
<th>X(T)</th>
<th>Y(T)</th>
<th>K(T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OXYGEN</td>
<td>0.24314</td>
<td>0.78058E-01</td>
<td>0.24314</td>
<td>6679.3</td>
</tr>
<tr>
<td>WATER</td>
<td>0.56674</td>
<td>0.88044</td>
<td>0.56674</td>
<td>1387.6</td>
</tr>
<tr>
<td>CO2</td>
<td>0.18713</td>
<td>0.41498E-01</td>
<td>0.18713</td>
<td>9669.6</td>
</tr>
</tbody>
</table>

BLOCK: B3  MODEL: FSPLIT

INLET STREAM: S8
OUTLET STREAMS: S9  S10  S11  S12  S13  S14

PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

TOTAL BALANCE
ENTHALPY (BTU/HR)  0.774410E+09  0.774410E+09  0.00000

*** RESULTS ***

STREAM= S9  SPLIT= 0.31309
S10  0.068448
S11  0.28453
S12  0.070137
S13  0.014650
S14  0.20914

BLOCK: B6  MODEL: PUMP

INLET STREAM: S302
OUTLET STREAM: S4

PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

TOTAL BALANCE
MOL (LB/MOL/HR)  2834.12  2834.12  0.00000
MOL (LB/HR)  124389.  124389.  0.233974E-15
ENTHALPY (BTU/HR)  -0.141655E+09  -0.141787E+09  0.934831E-03

*** 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 CO2E PRODUCTION 0.000000 LB/HR

*** INPUT DATA ***

EQUIPMENT TYPE: TURBINE
OUTLET PRESSURE (PSIA) 20.00000
DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:
LIQUID PHASE CALCULATION
NO FLASH PERFORMED
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000010000

*** RESULTS ***

VOLUMETRIC FLOW RATE (CUFT/HR) 4,416.56
PRESSURE CHANGE (PSI) -224.680
**_property**

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 (LBMOL/HR)</td>
<td>12920.3</td>
<td>12920.3</td>
<td>0.00000</td>
</tr>
<tr>
<td>MASS (LB/HR)</td>
<td>418458.</td>
<td>418458.</td>
<td>0.00000</td>
</tr>
<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.165617E+09</td>
<td>-0.140095E+09</td>
<td>-0.154101</td>
</tr>
</tbody>
</table>

---

**CO2 Equivalent Summary**

| Feed Streams CO2  | 7487.38 LB/HR |
| Product Streams CO2 | 7487.38 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**

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 | 7,221.68 |
Calculated Outlet Temp F | 294.195 |
Isentropic Temperature F | 262.506 |
Efficiency (Polyt/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, CFIT/HR | 2,532,020 |
Outlet Volumetric Flow Rate, CFIT/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: COMP

Inlet Stream: S206
Outlet Stream: S207
Property Option Set: UNIQUAC UNIQUAC / IDEAL GAS
### Mass and Energy Balance

<table>
<thead>
<tr>
<th>Component</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mole (lbmol/hr)</td>
<td>12920.3</td>
<td>12920.3</td>
<td>0.00000</td>
</tr>
<tr>
<td>Mass (lb/hr)</td>
<td>41845.8</td>
<td>41845.8</td>
<td>0.00000</td>
</tr>
<tr>
<td>Enthalpy (BTU/hr)</td>
<td>-0.140093E+09</td>
<td>-0.108743E+09</td>
<td>-0.223788</td>
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</tbody>
</table>

### CO2 Equivalent Summary

<table>
<thead>
<tr>
<th>Component</th>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Streams CO2</td>
<td>7487.38</td>
<td>7487.38</td>
</tr>
<tr>
<td>Product Streams CO2</td>
<td>7487.38</td>
<td>7487.38</td>
</tr>
<tr>
<td>Net Streams CO2 Production</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>Utilities CO2 Production</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>Total CO2 Production</td>
<td>0.00000</td>
<td>0.00000</td>
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### Input Data

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
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<tbody>
<tr>
<td>Isentropic Centrifugal Compressor</td>
<td></td>
</tr>
<tr>
<td>Outlet Pressure PSIA</td>
<td>300.00</td>
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<tr>
<td>Isentropic Efficiency</td>
<td>0.7200</td>
</tr>
<tr>
<td>Mechanical Efficiency</td>
<td>1.0000</td>
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</table>

### Results

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
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<tbody>
<tr>
<td>Indicated Horsepower Requirement</td>
<td>12,321.7</td>
</tr>
<tr>
<td>Brake Horsepower Requirement</td>
<td>12,321.7</td>
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<tr>
<td>Net Work Required</td>
<td>12,321.7</td>
</tr>
<tr>
<td>Power Losses</td>
<td>0.0</td>
</tr>
<tr>
<td>Isentropic Horsepower Requirement</td>
<td>8,871.59</td>
</tr>
<tr>
<td>Calculated Outlet Temp F</td>
<td>423.422</td>
</tr>
<tr>
<td>Isentropic Temperature F</td>
<td>388.640</td>
</tr>
<tr>
<td>Efficiency (polytrop/Isentropic)</td>
<td>0.7200</td>
</tr>
<tr>
<td>Outlet Vapor Fraction</td>
<td>1.0000</td>
</tr>
<tr>
<td>Head Developed, ft-lb/lb</td>
<td>41,977.3</td>
</tr>
<tr>
<td>Mechanical Efficiency Used</td>
<td>1.0000</td>
</tr>
<tr>
<td>Inlet Heat Capacity Ratio</td>
<td>1.12635</td>
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<tr>
<td>Inlet Volumetric Flow Rate, Cuft/hr</td>
<td>1,045,250.</td>
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<tr>
<td>Outlet Volumetric Flow Rate, Cuft/hr</td>
<td>408,144.</td>
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<tr>
<td>Inlet Compressibility Factor</td>
<td>1.0000</td>
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<tr>
<td>Outlet Compressibility Factor</td>
<td>1.0000</td>
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<tr>
<td>Av. Isent. Vol. Exponent</td>
<td>1.12037</td>
</tr>
<tr>
<td>Av. Isent. Temp Exponent</td>
<td>1.12037</td>
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<tr>
<td>Av. Actual Vol. Exponent</td>
<td>1.16824</td>
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<tr>
<td>Av. Actual Temp Exponent</td>
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</tbody>
</table>

### 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>Component</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
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</thead>
<tbody>
<tr>
<td>Mole (lbmol/hr)</td>
<td>2406.25</td>
<td>2406.25</td>
<td>0.00000</td>
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<tr>
<td>Mass (lb/hr)</td>
<td>103527.</td>
<td>103527.</td>
<td>0.00000</td>
</tr>
<tr>
<td>Enthalpy (BTU/hr)</td>
<td>-0.79171E+08</td>
<td>-0.88208E+08</td>
<td>0.81621E-01</td>
</tr>
</tbody>
</table>

### CO2 Equivalent Summary

<table>
<thead>
<tr>
<th>Component</th>
<th>IN</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Streams CO2</td>
<td>3.30868</td>
<td>3.30868</td>
</tr>
<tr>
<td>Product Streams CO2</td>
<td>3.30868</td>
<td>3.30868</td>
</tr>
<tr>
<td>Net Streams CO2 Production</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
<tr>
<td>Utilities CO2 Production</td>
<td>0.00000</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

Page 6
TOTAL CO2E PRODUCTION 0.00000  LB/HR

*** INPUT DATA ***

ISENTPHOTIC TURBINE
OUTLET PRESSURE PSIA 20.0000
ISENTPHOTIC 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
ISENTPHOTIC HORSEPOWER REQUIREMENT HP -3,840.84
CALCULATED OUTLET TEMP F 109.977
ISENTPHOTIC 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 COMPRESSION FACTOR 1.00000
OUTLET COMPRESSION FACTOR 1.00000
AV. ISENT. VOL. EXPONENT 1.11726
AV. ISENT. 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 ***

IN OUT RELATIVE DIFF.

TOTAL BALANCE
MOLE(LBMOL/HR) 4207.62 4207.62 0.00000
ENTHALPY(BTU/HR ) 0.486057e+08 0.365641e+08 0.247740

*** 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 ***

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

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP -4,732.51
BRAKE HORSEPOWER REQUIREMENT HP -4,732.51
NET WORK REQUIRED HP -4,732.51
POWER LOSSES HP 0.0
ISENTROPIC HORSEPOWER REQUIREMENT HP -6,572.93
CALCULATED OUTLET TEMP F 93.6757
ISENTROPIC TEMPERATURE F 19.7165
EFFICIENCY (POLYTR/ISENTR) USED 0.72000
OUTLET VAPOR FRACTION 1.00000
HEAD DEVELOPED FT-LBF/LB -73,485.6
MECHANICAL EFFICIENCY USED 1.00000
INLET HEAT CAPACITY RATIO 1.11580
INLET VOLUMETRIC FLOW RATE, CUFT/HR 56,278.7
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR 1,249,280
INLET COMPRESSIBILITY FACTOR 1.00000
OUTLET COMPRESSIBILITY FACTOR 1.00000
AV. ISENT. VOL. EXPONENT 1.13601
AV. ISENT. TEMP EXponent 1.13601
AV. ACTUAL VOL. EXPONENT 1.08343
AV. ACTUAL TEMP EXponent 1.08343

BLOCK: C303 MODEL: COMP

---

INLET STREAM: S308
OUTLET STREAM: S309
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

IN OUT RELATIVE DIFF.

TOTAL BALANCE
MOLE(LBMOL/HR) 4207.62 4207.62 0.00000
MASS(LB/HR) 177102. 177102. 0.00000
ENTHALPY(BTU/HR) 0.365641E+08 0.554198E+08 -0.340234

*** 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 CO2 PRODUCTION 0.000000 LB/HR
TOTAL CO2 PRODUCTION 0.000000 LB/HR

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR
OUTLET PRESSURE PSIA 250.000
ISENTROPIC EFFICIENCY 0.72000
MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT HP 7,410.58
BRAKE HORSEPOWER REQUIREMENT HP 7,410.58
NET WORK REQUIRED HP 7,410.58
POWER LOSSES HP 0.0
ISENTROPIC HORSEPOWER REQUIREMENT HP 5,355.62
CALCULATED OUTLET TEMP F 338.266
ISENTROPIC TEMPERATURE F 275.862
EFFICIENCY (POLYTR/ISENTR) USED 0.72000
OUTLET VAPOR FRACTION 1.00000
HEAD DEVELOPED, FT-LBF/LB 59,652.3
MECHANICAL EFFICIENCY USED 1.00000
INLET HEAT CAPACITY RATIO 1.134352
INLET VOLUMETRIC FLOW RATE, CUFT/HR 1,249,280
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR 144,119
INLET COMPRESSIBILITY FACTOR 1.00000

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### OUTLET COMPRESSIBILITY FACTOR

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>AV. ISENT. VOL. EXPONENT</td>
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<tr>
<td>AV. ISENT. TEMP EXPONENT</td>
<td>1.12700</td>
</tr>
<tr>
<td>AV. ACTUAL VOL. EXPONENT</td>
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<tr>
<td>AV. ACTUAL TEMP EXPONENT</td>
<td>1.16949</td>
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### BLOCK: c304 MODEL: COMPR

#### INLET STREAM: S313

#### OUTLET STREAM: S314

**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>
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#### *** CO2 EQUIVALENT SUMMARY ***

| Feed Streams CO2 | 2.97781 | LB/HR |
| 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 ***

#### GAS PHASE CALCULATION

NO FLASH PERFORMED

**ISENTROPIC CENTRIFUGAL COMPRESSOR**

| OUTLET PRESSURE PSIA | 72.5189 |
| ISENTROPIC EFFICIENCY | 0.72000 |
| MECHANICAL EFFICIENCY | 1.00000 |

### *** RESULTS ***

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### BLOCK: DC201 MODEL: RADFRAC

#### INLETS - S207 STAGE 19

#### OUTLETS - 3 STAGE 1

| OUTLET - S301 STAGE 20 |
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

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

**** 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 0.00010000000
OUTSIDE LOOP CONVERGENCE TOLERANCE 0.00010000000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST 1.000000
MOLAR REFUX RATIO 4.500000
MOLAR DISTILLATE RATE LB/HR 3,472.28

**** PROFILES ****

P-SPEC STAGE 1 PRES., PSIA 270.000

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

*** COMPONENT SPLIT FRACTIONS ***

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Page 10
CO2: 0.99189 8.112E-02
METHANE: 0.99989 1.0863E-03
ETHANE: 0.97478 2.522E-01
ETHENE: 0.99296 7.044E-02

*** 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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*** MASS FLOW PROFILES ***

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Page 11
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***** MASS-X-PROFILE *****

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***** HYDRAULIC PARAMETERS *****

```

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)^0.5(RHOL/RHOV)
QR = QV^0.5(RHOV/(RHOL-RHOU))
F FACTOR = QV^0.5(RHOU)

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
RHOU 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 ************
**Flooding Calculation Method**

- ~AP6A60.tmp
- b960

**Design Parameters**

- **Peak Capacity Factor**: 1.00000
- **System Foaming Factor**: 1.00000
- **Flooding Factor**: 0.80000
- **Minimum Column Diameter**: 1.00000
- **Minimum DC Area/Column Area**: 0.100000

**Tray Specifications**

- **Tray Type**: FLEXI
- **Number of Passes**: 4
- **Tray Spacing**: 2.00000

**Sizing Results @ Stage with Maximum Diameter**

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<th>FT</th>
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<td>Side Weir Length</td>
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<tr>
<td>Center Downcomer Width</td>
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<td>Center Weir Length</td>
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<td>Off-Center Short Weir Length</td>
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<td>Tray Center To ODIC Center</td>
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**Block**: DC301  **Model**: RADFRAC

**Inlets**: S301 Stage 45
**Outlets**: S303 Stage 1  S302 Stage 90
PROPERTY OPTION SET: 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 INSIDE 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 REFUX RATIO: 5.00000
MOLAR DISTILLATE RATE: 6,613.87 LB/MOL/HR

**** PROFILES ****

P-SPEC STAGE 1 PRES. (PSIA) 225.000

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

**** COMPONENT SPLIT FRACTIONS ****

<table>
<thead>
<tr>
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<tr>
<td>S303 S302</td>
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COMPONENT:

PROPANE: .42156 .57844
PROPENE: .99761 .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 ***

TOP STAGE TEMPERATURE [°F] 102.975
BOTTOM STAGE TEMPERATURE [°F] 121.194
TOP STAGE LIQUID FLOW [lb mol/hr] 33,069.3
BOTTOM STAGE LIQUID FLOW [lb mol/hr] 2,834.12
TOP STAGE VAPOR FLOW [lb mol/hr] 0.0
BOILUP VAPOR FLOW [lb mol/hr] 40,342.4
MOLAR REFLUX RATIO 5.0000
MOLAR BOILUP RATIO 14.2346
CONDENSER DUTY (w/o subcool) [BTU/hr] -0.226900e+09
REBOILER DUTY [BTU/hr] 0.220401e+09

*** MAXIMUM FINAL RELATIVE ERRORS ***

Dew Point 0.28803e-10 STAGE=90
Bubble Point 0.11372e-10 STAGE=52
Component Mass Balance 0.44259e-08 STAGE=45 component=water
Energy Balance 0.18842e-08 STAGE=1

*** PROFILES ***

**NOTE** Reported values for stage liquid and vapor rates are the flows from the stage including any side product.

<table>
<thead>
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<th>TEMPERATURE [°F]</th>
<th>PRESSURE [psia]</th>
<th>ENTHALPY [BTU/lbmol]</th>
<th>HEAT DUTY [BTU/hr]</th>
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**STAGE FLOW RATES** [lb mol/hr]

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**DEFINITIONS**

**MARANGONI INDEX** = SIGMA - SIGMATO
FLOW PARAM = (ML/MV) * SQRT(RHOV/RHOL)
QR = QV * SQRT(RHOL/(RHOV - RHOV))
F FACTOR = QV * SQRT(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 RHOV 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

**TEMPERATURE**

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**MASS FLOW**

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

******* SECTION 1 *******

STARTING STAGE NUMBER 2
ENDING STAGE NUMBER 89
FLOODING CALCULATION METHOD B960

DESIGN PARAMETERS

PEAK CAPACITY FACTOR 1.00000
SYSTEM FOAMING FACTOR 1.00000
FLOODING FACTOR 0.80000
MINIMUM COLUMN DIAMETER FT 1.00000
MINIMUM DC AREA/COLUMN AREA 0.100000

TRAY SPECIFICATIONS

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42  25.898  526.77  421.41  13.169
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44  25.901  526.91  421.53  13.173
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BLOCK: H000  MODEL: HEATER
-------------------------------------
INLET STREAM:  1
INLET HEAT STREAM:  52
OUTLET STREAM:  S110
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

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

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*** MASS AND ENERGY BALANCE ***

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*** CO2 EQUIVALENT SUMMARY ***

| FEED STREAMS CO2E | 12430.5 LB/HR |
| PRODUCT STREAMS CO2E | 12450.4 LB/HR |
| NET STREAMS CO2E PRODUCTION | -0.988521E-01 LB/HR |
| UTILITIES CO2E PRODUCTION | 0.00000 LB/HR |
| TOTAL CO2 PRODUCTION | -0.988521E-01 LB/HR |

*** INPUT DATA ***

| SPECIFIED PRESSURE | PSIA | 52.5000 |
| DUTY FROM INLET HEAT STREAM | BTU/HR | 0.683458E+08 |
| MAXIMUM NO. ITERATIONS | 30 |
| CONVERGENCE TOLERANCE | 0.00010000 |

*** RESULTS ***

| OUTLET TEMPERATURE | F | 1210.7 |
| OUTLET PRESSURE | PSIA | 52.500 |
| OUTLET VAPOR FRACTION | 1.0000 |

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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>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE (LEML/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 ***

Page 24
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 CO2E PRODUCTION 0.000000 LB/HR

*** INPUT DATA ***
SPECIFIED PRESSURE PSIA 72.5189
DUTY FROM INLET HEAT STREAMS BTU/HR 0.438439E+09
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***
OUTLET TEMPERATURE F 466.70
OUTLET PRESSURE PSIA 72.519
OUTLET VAPOUR 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>WATER</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>6.8627</td>
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</table>

BLOCK: H103 MODEL: HEATER

INLET STREAM: S112
OUTLET STREAM: S114
OUTLET WATER STREAM: 51
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 ***

<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>35313.9</td>
<td>35313.9</td>
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<tr>
<td>MASS(LB/HR)</td>
<td>824709.</td>
<td>824709.</td>
<td>0.282318E-15</td>
</tr>
<tr>
<td>ENTHALPY(BTU/HR)</td>
<td>-0.238191E+10</td>
<td>-0.287161E+10</td>
<td>0.170588</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 | 0.000000 | LB/HR |
| UTILITIES CO2E PRODUCTION | 0.000000 | LB/HR |
| TOTAL CO2E PRODUCTION | 0.000000 | LB/HR |

*** INPUT DATA ***
FREE WATER CONSIDERED
SPECIFIED TEMPERATURE F 176.000
SPECIFIED PRESSURE PSIA 34.8091
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** 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:

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(1)</th>
<th>X1(1)</th>
<th>X2(1)</th>
<th>Y(1)</th>
<th>K1(1)</th>
<th>K2(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPANE</td>
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<td>0.547E-01</td>
<td>0.00</td>
<td>0.358</td>
<td>26.4</td>
<td></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>
<td>32.0</td>
<td></td>
</tr>
<tr>
<td>HYDROGEN</td>
<td>0.941E-01</td>
<td>0.229E-03</td>
<td>0.00</td>
<td>0.240</td>
<td>0.433E+04</td>
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<tr>
<td>WATER</td>
<td>0.632</td>
<td>0.901</td>
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<td>0.201</td>
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<tr>
<td>CO</td>
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<td>0.00</td>
<td>0.429E-02</td>
<td>737.</td>
<td>0.447E-01</td>
</tr>
<tr>
<td>CO2</td>
<td>0.333E-02</td>
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<td>0.864E-02</td>
<td>116.</td>
<td>0.447E-01</td>
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<tr>
<td>METHANE</td>
<td>0.512E-03</td>
<td>0.148E-04</td>
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<td>0.133E-02</td>
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<tr>
<td>ETHANE</td>
<td>0.235E-03</td>
<td>0.304E-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>
<td>6613.87</td>
<td>0.00000</td>
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<tr>
<td>MASS(LB/HR)</td>
<td>282428.</td>
<td>282428.</td>
<td>0.00000</td>
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<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 CO2E 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 | 257.00 |
|                    | SPECIFIED PRESSURE | PSIA | 575.00 |
|                    | MAXIMUM NO. ITERATIONS | 30 |
|                    | CONVERGENCE TOLERANCE | 0.00010000 |

*** RESULTS ***

| OUTLET TEMPERATURE | F | 257.00 |
| OUTLET PRESSURE | PSIA | 575.00 |
| HEAT DUTY | BTU/HR | 0.54332E+08 |
| OUTLET VAPOR FRACTION | 1.0000 |

V-L PHASE EQUILIBRIUM:

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(1)</th>
<th>X1(1)</th>
<th>X2(1)</th>
<th>Y(1)</th>
<th>K1(1)</th>
<th>K2(1)</th>
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<tr>
<td>PROPANE</td>
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<tr>
<td>PROPENE</td>
<td>0.69124</td>
<td>0.65232</td>
<td>0.69124</td>
<td>1.9904</td>
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<tr>
<td>HYDROGEN</td>
<td>0.10023E-07</td>
<td>0.10195E-09</td>
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</table>

Page 26
**BLOCK: H302  MODEL: HEATER**

**INLET STREAM:** S315
**OUTLET STREAM:** S316

**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>Mole (LBMOL/HR)</td>
<td>4207.62</td>
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<tr>
<td>Mass (LB/HR)</td>
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<td>177102.</td>
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<tr>
<td>Enthalpy (BTU/HR)</td>
<td>0.544198E+08</td>
<td>0.133028E+08</td>
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*** CO2 EQUIVALENT SUMMARY ***

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<th>LB/HR</th>
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<td>FEED STREAMS CO2E</td>
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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>
<tr>
<td>UTILITIES CO2 PRODUCTION</td>
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</tr>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
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*** INPUT DATA ***

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<tbody>
<tr>
<td>TWO PHASE TP FLASH</td>
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</tr>
<tr>
<td>SPECIFIED TEMPERATURE</td>
<td>F</td>
</tr>
<tr>
<td>SPECIFIED PRESSURE</td>
<td>PSIA</td>
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<tr>
<td>MAXIMUM NO. ITERATIONS</td>
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</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
<td>0.00010000</td>
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</tbody>
</table>

*** RESULTS ***

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE</td>
<td>F</td>
</tr>
<tr>
<td>OUTLET PRESSURE</td>
<td>PSIA</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>BTU/HR</td>
</tr>
<tr>
<td>OUTLET VAPOR FRACTION</td>
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</tbody>
</table>

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>
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<tbody>
<tr>
<td>PROPANE</td>
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<td>0.50000E-02</td>
<td>0.41000E-02</td>
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<td>PROPENE</td>
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<td>0.99590</td>
<td>0.91745</td>
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**BLOCK: H303  MODEL: HEATER**

**INLET STREAM:** RECY
**OUTLET STREAM:** S313

**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>
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<tbody>
<tr>
<td>Mole (LBMOL/HR)</td>
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*** CO2 EQUIVALENT SUMMARY ***

<table>
<thead>
<tr>
<th></th>
<th>LB/HR</th>
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</thead>
<tbody>
<tr>
<td>FEED STREAMS CO2E</td>
<td>2.97781</td>
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</tbody>
</table>

Page 27
### PRODUCT STREAMS CO2
-AP6A60.tmp

<table>
<thead>
<tr>
<th>Stream</th>
<th>CO2 Production (LB/HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
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<tr>
<td>UTILITY</td>
<td>0.00000</td>
</tr>
<tr>
<td>NET</td>
<td>0.00000</td>
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</tbody>
</table>

### TWO PHASE TP FLASH

<table>
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</thead>
<tbody>
<tr>
<td>SPECIFIED TEMPERATURE</td>
</tr>
<tr>
<td>SPECIFIED PRESSURE</td>
</tr>
<tr>
<td>MAXIMUM NO. ITERATIONS</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
</tr>
</tbody>
</table>

### 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>COMPONENT</th>
<th>F(I)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>K(I)</th>
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<tbody>
<tr>
<td>PROPANE</td>
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<tr>
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<td>0.12650E-07</td>
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<tr>
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<td>0.56883</td>
<td>0.41238E-02</td>
<td>0.23315E-01</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>
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<tr>
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<td>52.512</td>
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**BLOCK:** HX101  **MODEL:** HEATX

---

**HOT SIDE:**

**INLET STREAM:** S110
**OUTLET STREAM:** S111
**PROPERTY OPTION SET:** UNIQUAC
**COLD SIDE:**

**INLET STREAM:** S105
**OUTLET STREAM:** S15
**PROPERTY OPTION SET:** UNIQUAC

* CALCULATED HOT SIDE FEED TEMPERATURE INCONSISTENT WITH INLET

---

### MASS AND ENERGY BALANCE

<table>
<thead>
<tr>
<th>Component</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE</td>
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</tr>
<tr>
<td>MASS</td>
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<tr>
<td>ENTHALPY</td>
<td>-0.452923E+10</td>
<td>-0.452925E+10</td>
<td>0.421118E-15</td>
</tr>
</tbody>
</table>

Page 28
*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E  12433.3  LB/HR
PRODUCT STREAMS CO2E  12433.3  LB/HR
NET STREAMS CO2E PRODUCTION  0.00000  LB/HR
UTILITIES CO2E PRODUCTION  0.00000  LB/HR
TOTAL CO2E PRODUCTION  0.00000  LB/HR

*** INPUT DATA ***

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

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

FLOW DIRECTION AND SPECIFICATION:
  COUNTERCURRENT HEAT EXCHANGER
SPECIFIED COLD OUTLET TEMP
SPECIFIED VALUE  F  1094.0000
LMTD CORRECTION FACTOR  1.00000

PRESSURE SPECIFICATION:
  HOT SIDE OUTLET PRESSURE  PSIA  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 VAPOR  COLD LIQUID  BTU/HR-SQFT-R  149.6937
  HOT LIQUID  COLD 2-PHASE  BTU/HR-SQFT-R  149.6937
  HOT 2-PHASE  COLD 2-PHASE  BTU/HR-SQFT-R  149.6937
  HOT VAPOR  COLD 2-PHASE  BTU/HR-SQFT-R  149.6937
  HOT LIQUID  COLD VAPOR  BTU/HR-SQFT-R  149.6937
  HOT 2-PHASE  COLD VAPOR  BTU/HR-SQFT-R  149.6937
  HOT VAPOR  COLD VAPOR  BTU/HR-SQFT-R  149.6937

*** OVERALL RESULTS ***

STREAMS:

S110  ------->  HOT  ------->  S111
T=  1.2107D+03  T=  4.6081D+02
P=  5.2500D+01  P=  5.2500D+01
V=  1.0000D+00  V=  1.0000D+00

S15  ------->  COLD  ------->  S105
T=  1.0940D+03  T=  2.8827D+02
P=  7.2519D+01  P=  7.2519D+01
V=  1.0000D+00  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:

Page 29
**Average Coefficient (Dirty)**

<table>
<thead>
<tr>
<th></th>
<th>BTU/HR-SQFT-R</th>
<th>149.6937</th>
</tr>
</thead>
<tbody>
<tr>
<td>( UA ) (Dirty)</td>
<td>BTU/HR-R</td>
<td>2757861.9035</td>
</tr>
</tbody>
</table>

**Log-Mean Temperature Difference:**

- \( \text{LMTD Correction Factor} \) = 1.0000
- \( \text{LMTD (Corrected)} \) = 143.2685
- \( \text{Number of Shells in Series} \) = 1

**Pressure Drop:**

- \( \text{Hot Side, Total Pressure Drop} \) = 0.0000 PSI
- \( \text{Cold Side, Total Pressure Drop} \) = 0.0000 PSI

*** Zone Results ***

**Temperature Leaving Each Zone:**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HOT IN</strong></td>
<td><strong>VAP</strong></td>
<td><strong>HOT OUT</strong></td>
</tr>
<tr>
<td>1210.7</td>
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<td>460.8</td>
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<td><strong>VAP</strong></td>
<td><strong>COLDIN</strong></td>
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**Zone Heat Transfer and Area:**

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**HEATX COLD-TQU HX101 TQCURV INLET**

- **Pressure Profile:** CONSTANT
- **Pressure Drop:** 0.0 PSI
- **Property Option Set:** UNIQVAC / IDEAL GAS

<table>
<thead>
<tr>
<th>DUTY</th>
<th>PRES</th>
<th>TEMP</th>
<th>VFRAC</th>
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BLOCK: HX301  MODEL: HEATX
HOT SIDE:
INLET STREAM: S309
OUTLET STREAM: S315
PROPERTY OPTION SET:
  UNIQAC  UNIQAC / IDEAL GAS
COLD SIDE:
---------------
INLET STREAM:  S304
OUTLET STREAM: S305
PROPERTY OPTION SET:
  UNIQAC  UNIQAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

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*** CO2 EQUIVALENT SUMMARY ***

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*** 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 BTU/HR 1000000.0000
  LMTD CORRECTION FACTOR 1.0000

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

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

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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
PER CENT 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
COLDSIDE, TOTAL  | PSI  | 0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

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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 / IDEAL GAS

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<th>VFRAC</th>
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HEATX HOT-QCURV HX301 TQCURV INLET

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

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<tr>
<th>Duty</th>
<th>Pres</th>
<th>Temp</th>
<th>Vfrac</th>
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**BLOCK: M301  MODEL: SEP**

**INLET STREAM:** S306

**OUTLET STREAMS:** S307  S310

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

*** MASS AND ENERGY BALANCE ***

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<th>RELATIVE DIFF.</th>
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*** CO2 EQUIVALENT SUMMARY ***

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<th>PRODUCT STREAMS CO2E</th>
<th>UTILITIES CO2E PRODUCTION</th>
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*** INPUT DATA ***

FLASH SPECS FOR STREAM S307

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FLASH SPECS FOR STREAM S310

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<th>CONVERGENCE TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>30</td>
<td>0.000100000</td>
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</table>

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

<table>
<thead>
<tr>
<th>STREAM SUBSTREAM SPLIT FRACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>S307 MIXED 0.010304</td>
</tr>
<tr>
<td>S310 MIXED 0.98970</td>
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</table>

COMPONENT = PROPENE

<table>
<thead>
<tr>
<th>STREAM SUBSTREAM SPLIT FRACTION</th>
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</thead>
<tbody>
<tr>
<td>S307 MIXED 0.91575</td>
</tr>
<tr>
<td>S310 MIXED 0.084250</td>
</tr>
</tbody>
</table>

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:  UNIQVAC UNIQVAC / 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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<tr>
<td>TOTAL BALANCE</td>
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<td></td>
</tr>
<tr>
<td>MOLE(LBMOL/HR)</td>
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<tr>
<td>MASS(LB/HR)</td>
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<tr>
<td>ENTHALPY(BTU/HR)</td>
<td>-0.185147E+09</td>
<td>-0.185147E+09</td>
<td>0.16996E-15</td>
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</table>

*** 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
-AP6A60.tmp

HYDROGEN
OXYGEN
WATER
CO
CO2
METHANE
ETHANE
ETHENE

*** RESULTS ***

HEAT DUTY BTU/HR -0.25422E-07

COMPONENT = PROPANE
STREAM = S205
SUBSTREAM MIXED
SPLIT FRACTION 1.00000

COMPONENT = PROPENE
STREAM = S205
SUBSTREAM MIXED
SPLIT FRACTION 1.00000

COMPONENT = HYDROGEN
STREAM = S205
SUBSTREAM MIXED
SPLIT FRACTION 0.0010000
S205 MIXED 0.99900

COMPONENT = WATER
STREAM = S204
SUBSTREAM MIXED
SPLIT FRACTION 0.29000
S205 MIXED 0.71000

COMPONENT = CO
STREAM = S205
SUBSTREAM MIXED
SPLIT FRACTION 1.00000

COMPONENT = CO2
STREAM = S204
SUBSTREAM MIXED
SPLIT FRACTION 0.94000
S205 MIXED 0.06000

COMPONENT = METHANE
STREAM = S205
SUBSTREAM MIXED
SPLIT FRACTION 1.00000

COMPONENT = ETHANE
STREAM = S205
SUBSTREAM MIXED
SPLIT FRACTION 1.00000

COMPONENT = ETHENE
STREAM = S205
SUBSTREAM MIXED
SPLIT FRACTION 1.00000

BLOCK: MX101 MODEL: MIXER

-----------------------------
INLET STREAMS: S101 S116
OUTLET STREAM: S102
PROPERTY OPTION SET: UNIQUAC UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

TOTAL BALANCE MOLE(LBMOL/HR) 21396.9 21396.9 0.00000

Page 37
MASS (LB/HR)  385471  385471  0.00000
ENTHALPY (BTU/HR)  -0.259449E+10 -0.259449E+10 -0.183788E-15

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

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

BLOCK: MX102 MODEL: MIXER
----------------------------------------
INLET STREAMS: S104  S103  S314
OUTLET STREAM: S105
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>30996.5</td>
<td>30996.5</td>
<td>-0.11736E-15</td>
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<tr>
<td>MASS (LB/HR)</td>
<td>807550.0</td>
<td>807550.0</td>
<td>-0.103508E-08</td>
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<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.256099E+10</td>
<td>-0.256099E+10</td>
<td>0.947987E-08</td>
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</table>

*** CO2 EQUIVALENT SUMMARY ***
FEED STREAMS CO2E  2.97781 LB/HR
PRODUCT STREAMS CO2E  2.97781 LB/HR
NET STREAMS CO2E PRODUCTION  -0.351163E-06 LB/HR
UTILITIES CO2E PRODUCTION  0.00000 LB/HR
TOTAL CO2E PRODUCTION  -0.351163E-06 LB/HR

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

BLOCK: MX301 MODEL: MIXER
----------------------------------------
INLET STREAMS: S311  S4
OUTLET STREAM: S312
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>
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<tr>
<td>TOTAL BALANCE</td>
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<td>5240.37</td>
<td>0.000000</td>
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<tr>
<td>MASS (LB/HR)</td>
<td>229716.0</td>
<td>229716.0</td>
<td>-0.253390E-15</td>
</tr>
<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.227995E+09</td>
<td>-0.227995E+09</td>
<td>0.392144E-15</td>
</tr>
</tbody>
</table>

*** 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 ***
### TWO PHASE FLASH

**MAXIMUM NO. ITERATIONS**: 30
**CONVERGENCE TOLERANCE**: 0.00010000
**OUTLET PRESSURE**: MINIMUM OF INLET STREAM PRESSURES

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

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

#### TOTAL BALANCE

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
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<tbody>
<tr>
<td>MOL (LB/MOL/HR)</td>
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<td>19523.0</td>
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<tr>
<td>MASS (LB/HR)</td>
<td>351712.5</td>
<td>351712.5</td>
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<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.236430e+10</td>
<td>-0.236424e+10</td>
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</table>

#### 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 PSI | 72.5189 |
| DRIVER EFFICIENCY   | 1.00000 |

#### FLASH SPECIFICATIONS:

| LIQUID PHASE CALCULATION | NO FLASH PERFORMED |
| TOLERANCE                | 0.00010000 |

#### 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**: UNIQUAC UNIQUAC / IDEAL GAS

#### TOTAL BALANCE

<table>
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<tr>
<th>IN</th>
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<tbody>
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<td>6613.87</td>
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<tr>
<td>MASS (LB/HR)</td>
<td>282428.5</td>
<td>282428.5</td>
</tr>
<tr>
<td>ENTHALPY (BTU/HR)</td>
<td>-0.866623e+08</td>
<td>-0.858981e+08</td>
</tr>
</tbody>
</table>

#### 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 0.000000 LB/HR
TOTAL CO2E PRODUCTION 0.000000 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 0.000100000

*** 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(LMBDL/HR) 30996.5  33892.2  2895.75  0.00000
MASS(LB/HR) 807550.  807550. -0.144159E-15
ENTHALPY(ITU/HR) -0.216583E+10 -0.200387E+10 -0.747796E-01

*** CO2 EQUVALENT SUMMARY ***

FEED STREAMS CO2E 2.97781 LB/HR
PRODUCT STREAMS CO2E 5085.66 LB/HR
NET STREAMS CO2E PRODUCTION 5082.68 LB/HR
UTILITIES CO2E PRODUCTION 0.000000 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

Page 40
REACTI ON # 2:
SUBSTREAM:MIXED KEY COMP:PROPANE CONV FRAC: 0.2000E-02

REACTI ON # 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 0.00010000
SERIES REACTIONS
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES 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:

<table>
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<tbody>
<tr>
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<tr>
<td>2</td>
<td>12.673</td>
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V-L PHASE EQUILIBRIUM:

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<th>K(I)</th>
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<tr>
<td>PROPANE</td>
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<tr>
<td>WATER</td>
<td>0.63190</td>
<td>0.77998</td>
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<td>209.51</td>
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<td>CO</td>
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<td>CO2</td>
<td>0.15217E-05</td>
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<td>METHANE</td>
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<td>0.60196E-04</td>
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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 *
********************************************************************

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

MOLE (LB/HR) 34642.2 35660.4 1018.15 0.00000
MASS (LB/HR) 831549. 831549. 0.279996E-15
ENTHALPY (BTU/HR) -0.199808E+10 -0.199808E+10 -0.357972E-15

*** CO2 EQUIVALENT SUMMARY ***
FEED STTHRES CO2E 5085.66 LB/HR
PRODUCT STTHRES CO2E 12450.5 LB/HR
NET STTHRES CO2E PRODUCTION 7344.80 LB/HR
UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2E PRODUCTION 7344.80 LB/HR

*** INPUT DATA ***

STOCHIOMETRY 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 :
PROPANE -1.00 OXYGEN -5.00 WATER 4.00 CO2 3.00

REACTION # 4:
SUBSTREAM MIXED :
PROPANE -1.00 OXYGEN -3.50 WATER 4.00 CO 3.00

REACTION # 5:
SUBSTREAM MIXED :
HYDROGEN -1.00 ETHANE 1.00 ETHENE -1.00

REACTION # 6:
SUBSTREAM MIXED :
HYDROGEN -1.00 OXYGEN -0.50 WATER 1.00

REACTION CONVERSION SPECS: NUMBER= 5
REACTION # 1:
SUBSTREAM:MIXED KEY COMP:PROPANE CONV FRAC: 0.2238
REACTION # 2:
SUBSTREAM:MIXED KEY COMP:PROPANE CONV FRAC: 0.1100E-02
REACTION # 3:
SUBSTREAM:MIXED KEY COMP:PROPANE CONV FRAC: 0.8000E-02
REACTION # 4:
SUBSTREAM:MIXED KEY COMP:PROPANE CONV FRAC: 0.4000E-02
REACTION # 5:
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 1094.00
SPECIFIED PRESSURE PSIA 56.3000
MAXIMUM NO. ITERATIONS 30
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:

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<tr>
<th>REACTION NUMBER</th>
<th>REACTION LBMOL/HR</th>
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V-L PHASE EQUILIBRIUM:

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<th>Y(I)</th>
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<td>2528.6</td>
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<tr>
<td>WATER</td>
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<td>0.80160</td>
<td>0.63439</td>
<td>382.22</td>
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<tr>
<td>CO</td>
<td>0.16368E-02</td>
<td>0.52325E-03</td>
<td>0.16368E-02</td>
<td>1510.8</td>
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<tr>
<td>CO2</td>
<td>0.33015E-02</td>
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<td>1983.7</td>
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<tr>
<td>METHANE</td>
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<td>0.19539E-03</td>
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<tr>
<td>ETHANE</td>
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<td>112.6</td>
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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 ***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
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</thead>
<tbody>
<tr>
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<td>21692.2</td>
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<td>390791.</td>
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<td>ENTHALPY(BTU/HR)</td>
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<td>-0.262700E+10</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

*** CO2 EQUIVALENT SUMMARY ***

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

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

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

BLOCK: T101
MODEL: COMP

INLET STREAM: S111
OUTLET STREAM: S112

PROPERTY OPTION SET: UNIQUAC / IDEAL GAS

*** MASS AND ENERGY BALANCE ***

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<tr>
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<td>ENTHALPY (BTU/HR)</td>
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<td>-0.238191E+10</td>
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*** CO2 EQUIVALENT SUMMARY ***

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<tr>
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*** 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 (POLYTR/ISENTR) USED | 0.72000
OUTLET VAPOR FRACTION | 1.00000
HEAT DEVELOPED FT-LBF/LB | -24,241.6
MECHANICAL EFFICIENCY USED | 1.00000
INLET HEAT CAPACITY RATIO | 1.18360
INLET VOLUMETRIC FLOW RATE, CFU/HR | 6,644,400.
OUTLET VOLUMETRIC FLOW RATE, CFU/HR | 9,571,390.
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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### Stream Report

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**SUBSTREAM: MIXED**

**PHASES:** 
- LIQUID
- VAPOR

**COMPONENTS: LB/MOL/HR**

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**COMPONENTS: LB/HR**

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**MIXED SUBSTREAM PROPERTIES:**

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SUBSTREAM: MIXED

PHASE: LIQUID LIQUID LIQUID VAPOR VAPOR

COMPONENTS: LBMOL/HR

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COMPONENTS: LB/HR

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TOTAL FLOW:

LBMOL/HR 2.1692+04 1873.9292 2.1397+04 4883.2391 2.1397+04

CFT/HR 6441.9834 544.0608 6533.9742 3.8781+05 2.9332+06

STATE VARIABLES:

| Temp F | 176.0000 | 77.0000 | 165.7922 | 77.0000 | 466.6963 |
| Pres PSIA | 34.8091 | 72.5189 | 72.5189 | 72.5189 | 72.5189 |
| VFRAC  | 0.0 |
| LFRAC  | 0.0 | 1.0000 | 1.0000 | 0.0 | 0.0 |
| SFRAC  | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

ENTHALPY:

BTU/LBMOL -1.2110+05 -1.2287+05 -1.2126+05 -4.5004+04 -1.0076+05

BTU/LB 6722.2463 -6820.4298 -6730.7001 -1020.5862 -5593.2896

BTU/HR -2.6270+09 -2.3025+08 -2.5945+09 -2.1977+08 -2.1561+09

ENTROPY:


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

DENSITY:

LBMOL/CFT 3.3673 3.4443 3.2747 1.2592-02 7.2948-03

LB/CFT 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:

| TEMP F | 176.0000 | 77.0000 | 165.7822 | 77.0000 | 466.6963 |
| PRES PSIA | 34.8091 | 72.5189 | 72.5189 | 72.5189 | 72.5189 |
| HFLUX BTU/HR | -2.6270+09 | -2.3025+08 | -2.5945+09 | -2.1977+08 | -2.1561+09 |

S105 S108 S109 S110 S111

STREAM ID | S105 | S108 | S109 | S110 | S111 |
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| S112 | S114 | S116 | S15 | S202 |

**FROM:**

| T101 | H101 | P101 | MX101 | AD201 |

**TO:**

| M103 | AD201 | MX101 | R101 | ----- |

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S203 S204 S205 S206 S207
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SUBSTREAM: MIXED

PHASE: VAPOR VAPOR VAPOR VAPOR VAPOR VAPOR

Page 4
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Page 5
-APF311.tmp

| HYDROGEN  | 0.0 | 6.6292-05 | 0.0 | 6.6292-05 | 6.6292-05 |
| 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 | 5.5859-04 | 0.0 | 5.5859-04 | 5.5859-04 |
| CO2       | 0.0 | 5.7303-02 | 0.0 | 5.7303-02 | 5.7303-02 |
| METHANE   | 0.0 | 1.9617-03 | 0.0 | 1.9617-03 | 1.9617-03 |
| ETHANE    | 0.0 | 0.2072    | 8.4722-28 | 0.2072 | 0.2072 |
| ETHENE    | 0.0 | 7.0584-02 | 0.0 | 7.0584-02 | 7.0584-02 |

**COMPONENTS: LB/HR**

| PROPANE   | 0.0 | 2.1357+05 | 1.2354+05 | 9.0036+04 | 9.0036+04 |
| PROPENE   | 0.0 | 1.9284+05 | 460.8995 | 1.9284+05 | 1.9284+05 |
| HYDROGEN  | 0.0 | 1.3364-04 | 0.0       | 1.3364-04 | 1.3364-04 |
| OXYGEN    | 0.0 | 0.0       | 0.0       | 0.0       | 0.0       |
| WATER     | 3.9079+04 | 388.3114 | 389.3114 | 0.0 | 0.0 |
| CO        | 0.0 | 1.5646-02 | 0.0       | 1.5646-02 | 1.5646-02 |
| CO2       | 0.0 | 2.5219    | 2.7305-34 | 2.5219    | 2.5219    |
| METHANE   | 0.0 | 3.1472-02 | 0.0       | 3.1472-02 | 3.1472-02 |
| ETHANE    | 0.0 | 6.2314    | 2.5476-26 | 6.2314    | 6.2314    |
| ETHENE    | 0.0 | 1.9802    | 1.4771-35 | 1.9802    | 1.9802    |

**TOTAL FLOW:**

| LB/MOL/HR | 2169.2211 | 9447.9886 | 2834.1208 | 6613.8679 | 6613.8679 |
| LB/HR     | 3.9079+04 | 4.0682+05 | 1.2439+05 | 2.8243+05 | 2.8243+05 |
| CUF/T/HR  | 665.6167 | 1.4414+04 | 4416.5585 | 9476.0785 | 9538.6338 |

**STATE VARIABLES:**

| TEMP F    | 173.8599 | 124.8463 | 121.1944 | 102.9747 | 105.9465 |
| PRES PSIA | 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/MOL | -1.2130+05 | -2.3480+04 | -4.9982+04 | -1.3106+04 | -1.2088+04 |
| BTU/LB     | -6722.2463 | -165.3003 | -1138.8233 | -306.9180 | -304.1419 |
| BTU/HR     | -2.6270+08 | -2.2184+08 | -1.4165+08 | -1.7609+08 | -312.14 |

**ENTROPY:**

| BTU/LB/MOL-R | -35.9555 | -61.3611 | -77.2836 | -56.7877 | -56.5991 |
| BTU/LB-R     | -1.9958 | -1.4251 | -1.7009 | -1.3298 | -1.3214 |

**DENSITY:**

| LB/MOL/CUFT | 3.2188 | 0.6543 | 0.6417 | 0.6980 | 0.6934 |
| LB/CUFT     | 58.7076 | 26.1711 | 28.1643 | 29.8043 | 29.6089 |
| AVG MW      | 18.0153 | 43.0586 | 43.8899 | 42.7024 | 42.7024 |

**MIXED SUBSTREAM PROPERTIES:**

*** ALL PHASES ***

| TEMP F | 173.8599 | 124.8463 | 121.1944 | 102.9747 | 105.9465 |
| PRES PSIA | 34.8091 | 281.9800 | 244.6800 | 225.0000 | 575.0000 |
| HFLMX BTU/HR | -2.6270+08 | -2.2184+08 | -1.4165+08 | -5.6682+07 | -8.5898+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 PHASE:**

**COMPONENTS: LB/MOL/HR**

| PROPENE   | 4571.7475 | 4571.7475 | 4186.5784 | 4186.5784 | 4186.5784 |
| HYDROGEN  | 6.6292-05 | 6.6292-05 | 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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**Total Flow:**

- LBMOL/LR: 6613.8679
- CFT/LR: 2.8243+05
- CFT/HR: 9619.8001
- BU/LB: 8.8463+04
- BU/HR: 5.6279+04
- BU/HR: 1.2493+06
- BU/HR: 1.4412+05

**State Variables:**

- Temp: 0.0534
- Pres: 757.0000
- VFRAC: 0.0
- LFRAC: 0.0
- SFRAC: 0.0

**Enthalpy:**

- BTU/LB: -1.2836+04
- BTU/LB: -300.6006
- BTU/LB: -8.4989+07

**Entropy:**

- BTU/LB: -56.36+04
- BTU/LB: -1.3198

**Density:**

- LBMOL/CFT: 42.7024
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- LBMOL/CFT: 42.7024

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MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
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STREAM ID: S315 S316 S4 S6 S7
FROM : HX301 HX302 B6 B2 ----
TO : HX302 ---- MX301 B2 ----

SUBSTREAM: MIXED PHASE:

COMPONENTS: LB/HR/mol

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STATE VARIABLES:
- TEMP: 1094.0000
- PRES: 56.3000
- VFRAC: 1.0000
- LFRAC: 0.00
- SFRAC: 0.00

ENTHALPY:
- BTU/LB/MOL: -5.7947
- BTU/LB: -2485.0316
- BTU/HR: -2.0664

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

DENSITY:
- LB/FT³: 3.3767
- LB/FT³: 3.8740
- AVG MW: 23.3186
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**TOTAL FLOW:**
- LB/MOL/HR: 1.9523E+04
- LB/HR: 3.5171E+05
- Cubic FT/HR: 5990.9099

**STATE VARIABLES:**
- TEMP (F): 173.8599
- PRES (PSIA): 34.8091
- VFRAC: 0.0
- LFRAC: 1.0000
- SFRC: 0.0

**ENTHALPY:**
- 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/CFUFT: 3.2588
- LB/CUFT: 58.7076
- AVG MN: 18.0153

**MIXED SUBSTREAM PROPERTIES:**

*** ALL PHASES ***
- TEMP (F): 173.8599
- PRES (PSIA): 34.8091
- HFLMN (BTU/HR): -2.3643E+09
STREAM ID         3
FROM :            DC201
TO :              B2

SUBSTREAM: MIXED PHASE:
COMPONENTS: LB/MOL/HR VAPOR
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             308.3602
METHANE        287.0284
ETHANE         240.8459
ETHENE         279.1268

TOTAL FLOW:
LB/MOL/HR      3472.2806
LB/HR          1.1641x04
CUFT/HR        5.0171x04

STATE VARIABLES:
TEMP            F        -96.1354
PRESS           PSIA    270.0000
VFRC            1.0000
LFRC            0.0
SFRC            0.0
ENTHALPY:
BTU/LB/MOL     -2412.5808
BTU/LB         -719.6493
BTU/HR         -8.3772x06

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
PRESS           PSIA    270.0000
HFLX            BTU/HR  -8.3772x06

PURGE

STREAM ID         PURGE
FROM :            B1

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TO : B2

SUBSTREAM: MIXED
PHASE: MIXED

COMPONENTS: LB/MOL/HR

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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/CUFT  | 4.6465-03 |
| LB/CUFT      | 0.2037   |
| AVG MW       | 43.8358  |

MIXED SUBSTREAM PROPERTIES:

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SUBSTREAM: MIXED
PHASE: MIXED
COMPONENTS: LB/MOL/HR
PROPANE 4340.0723
PROPENE 346.5097
HYDROGEN 5.9663-05
OXYGEN 0.0
WATER 19.4491
CO 5.0027-04
CO2 5.1573-02
METHANE 1.7656-03
ETHANE 0.1865
ETHENE 6.3526-02
COMPONENTS: LB/HR
PROPANE 1.9138+05
PROPENE 1.5002+04
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 2.0674+05
CUFT/HR 1.0150+06
STATE VARIABLES:
TEMP F -28.8264
PRES PSIA 20.0000
VFRC 0.9306
LFRAC 6.9996-02
SFRAC 0.0
ENTHALPY:
BTU/LB/MOL -4.3507+04
BTU/LB -992.5094
BTU/HR -2.0520+08
ENTROPY:
BTU/LB/MOL-R -66.7457
BTU/LB-R -1.5226
DENSITY:
LB/MOL/CUFT 4.6465-03
LB/CUFT 0.2037
AVG MW 43.8358

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F -28.8264
PRES PSIA 20.0000
HFLMX BTU/HR -2.0520+08
SI
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FROM: M103
TO: SP101
SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LB/MOL/HR
PROPANE 0.0
PROPANE  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
PROPANE  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
PRESS  PSIA  34.8091
VFRACT  0.0
LFRACT  1.0000
SFRACT  0.0

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

ENTROPY:
BTU/LB/MOL-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
PRESS  PSIA  34.8091
HFLMX  BTU/HR  -2.6270E+09

--

STREAM ID: S2
FROM: K102
TO: H000
CLASS: HEAT

STREAM ATTRIBUTES:
HEAT
Q  BTU/HR  6.8346E+07
TSEG  F  1094.0000
TEND  F  1094.0000
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 3.9079x10^4
CO 0.0
CO2 0.0
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

TOTAL FLOW:
LB/MOL/HR 2169.2211
LB/HR 3.9079x10^4
CFUFT/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 -1.2110x10^5
BTU/LB -6722.2463
BTU/HR -2.6270x10^8

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

DENSITY:
LB/CUFT 3.2588
LB/CFUFT 58.7076
AVG Mw 18.0153

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 173.8599
PRES PSIA 34.8091
HFLMX BTU/HR -2.6270x10^8

S4
--
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
SFRAC: 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
MFLHX (BTU/HR): -1.4179+08

---

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 7.65x10^{-4}
WATER 1.0100x10^5
CO 0.0
CO2 8.10x10^{-4}
METHANE 0.0
ETHANE 0.0
ETHENE 0.0

TOTAL FLOW:

LB MOL/HR 9840.5485
LB/HR 2.5860x10^5
CUFT/HR 1.1161x10^7

STATE VARIABLES:

TEMP F 1094.0000
PRES PSIA 24.7000
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:

BTU/LB MOL -8.1899x10^4
BTU/LB -3116.4657
BTU/HR -8.0593x10^8

ENTROPY:

BTU/LB MOL -R 5.2575
BTU/LB -R 0.2001

DENSITY:

LB MOL/CUFT 8.8166x10^{-4}
LB/CUFT 2.3170x10^{-2}
AVG Mn 26.2794

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

TEMP F 1094.0000
PRES PSIA 24.7000
HFLHX BTU/HR -8.0593x10^8

S7

STREAM ID S7
FROM : B7
TO : B2

SUBSTREAM: MIXED

PHASE: VAPOR
COMPONENTS: LB/MOL/HR
PROPAINE 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
PROPAINE 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 -3.4335E+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
HFLX BTU/HR -3.4335E+05

S8

STREAM ID S8
FROM : B2
TO : B3
CLASS: HEAT

STREAM ATTRIBUTES:
HEAT
Q BTU/HR 7.7441E+08
TBEG °F 7.1795
<table>
<thead>
<tr>
<th>STREAM ID</th>
<th>FROM</th>
<th>TO</th>
<th>CLASS</th>
<th>Q (BTU/HR)</th>
<th>TBEG</th>
<th>TEND</th>
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</thead>
<tbody>
<tr>
<td>S9</td>
<td>B3</td>
<td>H101</td>
<td>HEAT</td>
<td>2.7344e+08</td>
<td>7.1795</td>
<td>1094.0000</td>
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<tr>
<td>S10</td>
<td>B3</td>
<td></td>
<td>HEAT</td>
<td>5.3007e+07</td>
<td>7.1795</td>
<td>1094.0000</td>
</tr>
<tr>
<td>S11</td>
<td>B3</td>
<td></td>
<td>HEAT</td>
<td>2.2034e+08</td>
<td>7.1795</td>
<td>1094.0000</td>
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<tr>
<td>S12</td>
<td>B3</td>
<td></td>
<td>HEAT</td>
<td>5.4315e+07</td>
<td>7.1795</td>
<td>1094.0000</td>
</tr>
<tr>
<td>S13</td>
<td>B3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```
TO : ----
CLASS: HEAT

STREAM ATTRIBUTES:
HEAT
Q  BTU/HR  1.1345e+07
TEBG  F  7.1795
TEND  F  1094.0000

S14
----

STREAM ID  S14
FROM : B3
TO : ----
CLASS: HEAT

STREAM ATTRIBUTES:
HEAT
Q  BTU/HR  1.6196e+08
TEBG  F  7.1795
TEND  F  1094.0000

S15
----

STREAM ID  S15
FROM : MX301
TO : R101

SUBSTREAM: MIXED
PHASE: VAPOR
COMPONENTS: LBMOL/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:
LBMOL/HR  3.0996e+04
LB/HR  8.0755e+05
CUFT/HR  7.1265e+06

STATE VARIABLES:
TEMP  F  1094.0000
PRES  PSIA  72.5189
VFRAC  1.0000
LFRAC  0.0
```
SFRAC 0.0

ENTHALPY:
BTU/LB MOL -6.9874E+04
BTU/LB -2681.9833
BTU/HR -2.1658E+09

ENTROPY:
BTU/LB MOL-R -13.4731
BTU/LB -R -0.5171

DENSITY:
LB MOL/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 : H101
CLASS : HEAT

STREAM ATTRIBUTES:
HEAT Q BTU/HR 1.6500E+08

S101

---

STREAM ID S101
FROM : ----
TO : MX101

SUBSTREAM: MIXED PHASE:

LIQUID

COMPONENTS: LB MOL/HR
PROPANE 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
PROPANE 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/H  3.8547e+05
CUFT/H  5.44.0608
STATE VARIABLES:
    TEMP  F  77.0000
    PRES  PSIA  72.5189
    VFRAC  0.0
    LFRAC  1.0000
    SFRA  0.0
ENTHALPY:
    BTU/LBMOL  -1.2287e+05
    BTU/LB  -6820.4298
    BTU/H  -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
    PRES  PSIA  72.5189
    HFLMX  BTU/H  -2.3025e+08

S102
---

STREAM ID  S102
FROM  MK101
TO  M101

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: LB/HR
    PROPANE  0.0
    PROPE  0.0
    HYDROG  0.0
    OXYGEN  0.0
    WATER  2.1397e+04
    CO  0.0
    CO2  0.0
    ETHAN  0.0
    ETHER  0.0
COMPONENTS: LB/HR
    PROPANE  0.0
    PROPE  0.0
    HYDROG  0.0
    OXYGEN  0.0
    WATER  3.8547e+05
    CO  0.0
    CO2  0.0
    ETHAN  0.0
    ETHER  0.0

TOTAL FLOW:
LB/HR  3.8547e+05
LB/H  3.8547e+05
CUFT/HR    6533.9742
STATE VARIABLES:
  TEMP  F    165.7822
  PRES  PSIA  72.5189
  VFRAC  0.0
  LFRAC  1.0000
  SFRACT  0.0
ENTRALPY:
  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  18.0153

MIXED    SUBSTREAM PROPERTIES:

*** ALL PHASES ***
  TEMP  F    165.7822
  PRES  PSIA  72.5189
  HFLX  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
  CUFT/HR  3.8761E+05

STATE VARIABLES:
  TEMP  F    77.0000

Page 24
PRES PSIA 72.5189
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:
BTU/LBMOL -4.5004E+04
BTU/LB -1020.5862
BTU/HR -2.1977E+08

ENTROPY:
BTU/LBMOL-R -67.4897
BTU/LB-R -1.5305

DENSITY:
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
HFLMX BTU/HR -2.1977E+08

S104

---

STREAM ID S104
FROM : H101
TO : M102

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 2.9932E+06

STATE VARIABLES:
TEMP F 466.6963
PRES PSIA 72.5189
VFRAC 1.0000
LFRAC 0.0
### Phase Components: \( \text{lb mole/hr} \)

- **PROPANE**: 9223.3119
- **PROPENE**: 356.5092
- **HYDROGEN**: 5.9663-05
- **OXYGEN**: 0.0
- **WATER**: 2.1416+04
- **CO**: 5.0273-04
- **CO\(_2\)**: 5.3573-02
- **METHANE**: 1.7656-03
- **ETHANE**: 0.1865
- **ETHENE**: 6.3526-02

### Total Flow:

- **\( \text{lb mole/hr} \)**: 3.0996+04
- **\( \text{lb/hr} \)**: 8.6755+05
- **\( \text{cuft/hr} \)**: 3.4907+06

### State Variables:

- **\( T \text{ (F)} \)**: 288.2717
- **\( P \text{ (psia)} \)**: 72.5189
- **\( \text{VFRAC} \)**: 1.0000
- **\( \text{LFRAC} \)**: 0.0
- **\( \text{SFrac} \)**: 0.0
ENTHALPY:
  BTU/LB MOL  -8.2621E+04
  BTU/LB       -3171.2395
  BTU/HR       -2.5609E+09
ENTROPY:
  BTU/LB MOL-R -24.7911
  BTU/LB-R      -0.9516
DENSITY:
  LB MOL/CUFT  9.0350E-03
  LB/CUFT       0.2354
AVG MW        26.0329

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

  TEMP  F   288.2717
  PRES  PSIA  72.5189
  HFLX  BTU/HR -2.5609E+09

S108

----

STREAM ID S108
FROM        R101
TO           R102

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LB MOL/HR
  PROPANE 6323.7425
  PROPENE 3243.4059
  HYDROGEN 2883.0758
  OXYGEN  0.0
  WATER   2.1416E+04
  CO      5.0273E-04
  CO2     5.1573E-02
  METHANE 12.6746
  ETHANE  4.0074
  ETHENE  8.9154

COMPONENTS: LB/HR
  PROPANE 2.7886E+05
  PROPENE 1.3648E+05
  HYDROGEN 5811.9348
  OXYGEN  0.0
  WATER   3.8582E+05
  CO      1.4082E-02
  CO2     2.2697
  METHANE 203.3355
  ETHANE  120.5015
  ETHENE  250.1119

TOTAL FLOW:
  LB MOL/HR 3.3952E+04
  LB/HR     8.0755E+05
  CUFT/HR   7.7409E+06

STATE VARIABLES:
  TEMP  F  1094.0000
  PRES  PSIA  73.0000
  VFRAC  1.0000
  LFRAC  0.0
  SFRAC  0.0

ENTHALPY:
  BTU/LB MOL  -5.9125E+04
  BTU/LB       -2481.4258
MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

| Temp | F   | 1094.0000 |
| Pres | PSIA | 73.0000   |
| HFLMX | BTU/HR | -2.0039×10^9 |

S109
----

STREAM ID: S109
FROM: ----
TO: R102

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LB/MOL/HR

- PROPANE: 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

- PROPANE: 0.0
- PROPENE: 0.0
- HYDROGEN: 0.0
- OXYGEN: 2.399×10^4
- 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: 2.399×10^4
- CFU/HR: 1.713×10^5

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: 5.795×10^4

ENTROPY:

- BTU/LB/MOL-R: 4.7795
BTU/LB-R 0.1494
DENSITY:
LB/MOL/CUFT 4.3783-03
LB/CUFT 0.1401
AVG MW 31.9988
MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 1094.0000
PRES PSIA 73.0000
HFLMIX BTU/HR 5.7954+06

S110

---

STREAM ID S110
FROM : H000
TO : H0301

MAX CONV. ERROR: 1.4425-02
SUBSTREAM: MIXED PHASE: VAPOR
COMPONENTS: LB/MOL/HR
PROPANE 4844.6952
PROPENE 4633.5591
HYDROGEN 3322.1622
OXYGEN 0.0
WATER 2.2301+04
CO 58.3703
CO2 117.7321
METHANE 18.0742
ETHANE 8.2998
ETHENE 10.0203

COMPONENTS: LB/HR
PROPANE 2.1363+05
PROPENE 1.9498+05
HYDROGEN 6697.0804
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/MOL/HR 3.5314+04
LB/HR 8.2471+05
CUFT/HR 1.2076+07

STATE VARIABLES:
TEMP F 1210.7455
PRES PSIA 52.5000
VFrac 1.0000
LFrac 0.0
SFrac 0.0

ENTALPY:
BTU/LB/MOL -5.5737+04
BTU/LB -2386.6621
BTU/HR -1.9683+09

ENTROPY:
BTU/LB/MOL-R -5.3986
BTU/LB-R -0.2312

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DENSITY:
LB/MOL/CF = 2.9243-03
LB/CF = 6.8294-02
AVG Mw = 23.3537

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F = 1210.7455
PRES PSIA = 52.000
HFLX BTU/HR = -1.9688+09

S111

STREAM ID = S111
FROM = HX101
TO = T101

SUBSTREAM: MIXED PHASE:

VAPOR

COMPONENTS: LB/MOL/HR
PROPANE = 4844.6952
PROPENE = 4633.5591
HYDROGEN = 3322.1622
OXYGEN = 0.0
WATER = 2.2301+04
CO = 58.3703
CO2 = 137.7321
METHANE = 18.0742
ETHANE = 8.2998
ETHENE = 10.0203

COMPONENTS: LB/HR
PROPANE = 2.1363+05
PROPENE = 1.9458+05
HYDROGEN = 6697.0804
OXYGEN = 0.0
WATER = 4.0176+05
CO = 1634.9760
CO2 = 5181.3675
METHANE = 289.9595
ETHANE = 249.5730
ETHENE = 281.1069

TOTAL FLOW:
LB/MOL/HR = 3.5314+04
LB/HR = 2.4371+05
CUFT/HR = 6.6444+06

STATE VARIABLES:
TEMP F = 460.8083
PRES PSIA = 52.000
VFRAC = 1.0000
LFRAC = 0.0
SFRAC = 0.0

ENTHALPY:
BTU/LB/MOL = -6.6926+04
BTU/LB = -2865.7580
BTU/HR = -2.3634+09

ENTROPY:
BTU/LB/MOL = -14.1825
BTU/LB = -0.6079

DENSITY:
LB/MOL/CF = 5.3148-03
LB/CF = 0.1241

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**AVG MW**: 23.3537

**MIXED SUBSTREAM PROPERTIES:**

<table>
<thead>
<tr>
<th><strong>PHASE</strong></th>
<th><strong>COMPONENTS: LB/HR</strong></th>
</tr>
</thead>
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**TOTAL FLOW:**
- LB/HR: 3.5934+04
- LB/MOL/HR: 8.2471+05
- CUFT/HR: 9.5716+06

**STATE VARIABLES:**
- TEMP F: 419.5034
- PRES PSIA: 34.8091
- VFRAC: 1.0000
- LFRAC: 0.0
- SFRAC: 0.0

**ENTHALPY:**
- BTU/LB/MOL: -6.7450+04
- BTU/LB: -2888.1876
- BTU/HR: -2.3819+09

**ENTROPY:**
- BTU/LB/MOL-R: -13.9486
- BTU/LB-R: -0.5973

**DENSITY:**
- LB/MOL/CUFT: 3.6854-03
- LB/CUFT: 8.6362-02

**AVG MW**: 23.3537

**MIXED SUBSTREAM PROPERTIES:**
### ALL PHASES

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**S114**

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| COMPONENTS: LB/HR     |          |           |           |           |           |           |
| PROPANE               | 2.1363+05|           |           |           |           |           |
| PROPENE               | 1.9498+05|           |           |           |           |           |
| HYDROGEN              | 6697.0804|           |           |           |           |           |
| OXYGEN                | 0.0      |           |           |           |           |           |
| WATER                 | 1.0967+04|           |           |           |           |           |
| CO                    | 1634.9760|           |           |           |           |           |
| CO2                   | 5181.3675|           |           |           |           |           |
| METHANE               | 289.9595 |           |           |           |           |           |
| ETHANE                | 249.5730 |           |           |           |           |           |
| ETHENE                | 281.1069 |           |           |           |           |           |

**TOTAL FLOW:**

| LB/MOL/HR | 1.3622+04 |           |           |           |           |           |
| LB/HR     | 4.3392+05 |           |           |           |           |           |
| CUFT/HR   | 2.6695+06 |           |           |           |           |           |

**STATE VARIABLES:**

| TEMP | F | 176.0000 |           |           |           |           |
| PRES | PSIA | 34.8091   |           |           |           |           |
| VFRAC |          | 1.0000   |           |           |           |           |
| LFRAC |          | 0.0       |           |           |           |           |
| SFRAC |          | 0.0       |           |           |           |           |

**ENTHALPY:**

| BTU/LB/MOL | -1.7973+04 |           |           |           |           |           |
| BTU/LB     | -564.1584  |           |           |           |           |           |
| BTU/HR     | -2.4482+08 |           |           |           |           |           |

**ENTROPY:**

| BTU/LB/MOL-R | -31.5497 |           |           |           |           |           |
| BTU/LB-R     | -0.9904  |           |           |           |           |           |

**DENSITY:**

| LB/MOL/CUFT | 5.1027-03 |           |           |           |           |           |
| LB/CUFT     | 0.1625    |           |           |           |           |           |
| AVG MW      | 31.8550   |           |           |           |           |           |

**MIXED SUBSTREAM PROPERTIES:**

| TEMP | F | 176.0000 |           |           |           |           |

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Page 32
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**SUBSTREAM: MIXED**

**PHASE:** LIQUID

**COMPONENTS: LB/MOL/HR**

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**COMPONENTS: LB/HR**

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**TOTAL FLOW:**

| LB/MOL/HR | 1.9523e+04 |
| LB/HR     | 3.5171e+05 |
| CUFT/HR   | 5991.4609  |

**STATE VARIABLES:**

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**ENTHALPY:**

| BTU/LB/MOL | -1.2130e+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 ***

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- LBMOL/HR: 578.5612
- LB/HR: 1.0424+04
- CUFT/HR: 177.9018

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

ENTHALPY:
- BTU/LBMOL: -1.2102+05
- BTU/LB: -6717.3352
- BTU/HR: -7.0019+07

ENTROPY:
- BTU/LBMOL-R: -35.8847
- BTU/LB-R: -1.9918

DENSITY:
- LBMOL/CUFT: 3.2521
- LB/CUFT: 58.5918
- AVG Mw: 18.0164

MIXED SUBSTREAM PROPERTIES:

| TEMP F: 176.0000 |
| PRES PSIA: 34.8091 |
| HFLMX BTU/HR: -7.0019+07 |
STREAM ID: S203
FROM: AD201
TO: MEA201

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LBMOL/HR
PROPANE 4844.6952
PROPENE 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
PROPENE 1.9498+05
HYDROGEN 6697.0804
OXYGEN 0.0
WATER 548.3259
CO 1634.9760
CO2 5181.3675
METHANE 287.0999
ETHANE 247.0773
ETHENE 281.1069

TOTAL FLOW:
LBMOL/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/LBMOL -1.4195+04
BTU/LB -437.1884
BTU/HR -1.8515+08

ENTROPY:
BTU/LBMOL-R -32.8089
BTU/LB-R -1.0105

DENSITY:
LBMOL/CUFT 5.1027+03
LB/CUFT 0.1657
AVG Mw 32.4689

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

STREAM ID: S204
FROM: MEA201
TO: MEA201

Page 35
SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LB/MOL/HR

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MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

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S205

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FROM: MEA201
TO: CZ201

SUBSTREAM: MIXED

PHASE: VAPOR
COMPONENTS: LB/MOL/HR
PROPANE 4844.6952
PROPENE 4633.5391
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 6600.3833
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:
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PRES PSIA 34.8091
VFRAC 1.0000
LFRAC 0.0
SFRAC 0.0

ENTHALPY:
BTU/LBMOL -1.2818E+04
BTU/LB -395.7785
BTU/HR -1.6562E+08

ENTROPY:
BTU/LBMOL-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
HFLMX 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 4633.5391
<table>
<thead>
<tr>
<th>Component</th>
<th>LB/HR</th>
<th>LB/HR</th>
<th>Gas Mole Flow</th>
<th>Temp</th>
<th>Psia</th>
<th>VFRAC</th>
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<td></td>
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<td>CO</td>
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<td></td>
<td>247.0773</td>
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<tr>
<td>Ethene</td>
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<td></td>
<td></td>
<td>281.1069</td>
<td>100.0000</td>
<td></td>
</tr>
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</table>

**Total Flow:**
- LB/HR: 1.2920 + 4
- Cuft/HR: 4 + 1.0453 + 6

**State Variables:**
- Temp F: 294.1946
- VFRAC: 1.0000
- LFRAC: 0.0
- SFRAC: 0.0

**Enthalpy:**
- BTU/LB/ML: -1.0843 + 4
- BTU/LB: -384.7887
- BTU/HR: -1.4010 + 8

**Entropy:**
- BTU/LB/ML-R: -32.4714
- BTU/LB-R: -1.0026

**Density:**
- LB/ML/Cuft: 1.2361 + 02
- LB/Cuft: 0.0403

**AVG Mw:** 32.3877

**Mixed Substream Properties:**

<table>
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<tr>
<th>Temp</th>
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<th>Hflmx</th>
<th>BTU/HR</th>
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</thead>
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<td>BTU/HR</td>
<td></td>
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<tr>
<td>294.1946</td>
<td>100.0000</td>
<td>-1.4010 + 8</td>
<td></td>
</tr>
</tbody>
</table>

**Substream: Mixed**

**Phase:** Vapor

**Components:**
- Propane: 4844.6952
- Propene: 4633.5591
- Hydrogen: 3318.8401
- Oxygen: 0.0
- Water: 21.6101
CO: 58.3703
CO2: 7.0639
METHANE: 17.8994
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: 1694.9760
CO2: 310.8820
METHANE: 287.0599
ETHANE: 247.0773
ETHENE: 281.1069

TOTAL FLOW:
LB/MOL/HR: 1.2920e+04
LB/HR: 4.1846e+05
CUFT/HR: 4.0814e+05

STATE VARIABLES:
TEMP: 423.4221
PRES: 300.0000
VFRAC: 1.0000
LFRAC: 0.0
SFRAC: 0.0

ENTHALPY:
BTU/LB/MOL: -8416.4966
BTU/LB: -259.8669
BTU/HR: -1.0874e+08

ENTROPY:
BTU/LB/MOL: -31.6865
BTU/LB-R: -0.9783

DENSITY:
LB/MOL/CUFT: 3.1656e-02
LB/CUFT: 1.0253
AVG MW: 32.3877

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP: 423.4221
PRES: 300.0000
HFLMX: -1.0874e+08

S301

STREAM ID: S301
FROM: DC201
TO: DC301

SUBSTREAM: MIXED PHASE: LIQUID
COMPONENTS: LB/MOL/HR
PROPANE: 4843.3406
PROPENE: 4582.7003
HYDROGEN: 6.6292e-05
OXYGEN: 0.0
WATER: 21.6101
CO: 5.5859-04
CO2: 5.7303-02
METHANE: 1.9617-03

Page 39
ETHANE  0.2072
ETHENE  7.0584E-02
COMPONENTS: LB/HR
PROPANE  2.1357E+05
PROPENE  1.9284E+05
HYDROGEN  1.3364E+04
OXYGEN  0.0
WATER  389.3114
CO  1.5646E+02
CO2  2.5219
METHANE  3.1472E+02
ETHANE  6.2314
ETHENE  1.9802
TOTAL FLOW:
LB/HR  9447.9886
CUFT/HR  4.0682E+05
STATE VARIABLES:
TEMP  124.8463
PRES  281.9800
VFRAC  0.0
LFRAC  1.0000
SFRACT  0.0
ENTHALPY:
BTU/LBMOL  -2.3480E+04
BTU/LB  -545.3003
BTU/HR  -2.2184E+08
ENTROPY:
BTU/LBMOL-R  -61.3611
BTU/LB-R  -1.4251
DENSITY:
LB/HR  0.6443
LB/CUFT  28.1711
AVG MW  43.0586
MIXED SUBSTREAM PROPERTIES:
*** ALL PHASES ***
TEMP  124.8463
PRES  281.9800
HFLMX  2.2184E+08
S302
----
STREAM ID  S302
FROM :  DC301
TO :  B6
SUBSTREAM: MIXED PHASE:
COMPONENTS: LB/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  8.4722E-28
ETHENE  0.0
COMPONENTS: LB/HR

Page 40
PROPANE 1.2354e+05
PROPENE 460.8995
HYDROGEN 0.0
OXYGEN 0.0
WATER 389.3114
CO 0.0
CO2 2.7305e-34
METHANE 0.0
ETHANE 2.5476e-26
ETHENE 1.4771e-35
TOTAL FLOW:
LB/HR 2834.1208
CUFT/HR 1.2439e+05
STATE VARIABLES:
TEMP F 121.1944
PRES PSIA 244.6800
VFRC 0.0
SFC 1.0000
SFRAC 0.0
ENTALPY:
BTU/LBMOL -4.9982e+04
BTU/LB -1138.8023
BTU/HR -1.4165e+08
ENTROPY:
BTU/LBMOL -77.2836
BTU/LB -1.7609
DENSITY:
LB/ CUFT 0.6417
LB/CUFT 28.1643
AVG MW 43.8899

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 121.1944
PRES PSIA 244.6800
HFLMX BTU/HR -1.4165e+08

S303

STREAM ID S303
FROM : DC301
TO : P301

SUBSTREAM: MIXED PHASE:

COMPONENTS: LB/MOL/HR
PROPANE 2041.7827
PROPENE 4571.7475
HYDROGEN 6.6292e-05
OXYGEN 0.0
WATER 0.0
CO 5.5859-04
CO2 5.7303e-02
METHANE 1.9617e-03
ETHANE 0.2072
ETHENE 7.0584e-02

COMPONENTS: LB/HR
PROPANE 9.0036e+04
PROPENE 1.9238e+05
HYDROGEN 1.3564e+04
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<thead>
<tr>
<th>Component</th>
<th>Flow Rate (lbmol/hr)</th>
<th>Flow Rate (lb/hr)</th>
<th>Flow Rate (cuft/hr)</th>
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</thead>
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<td>Oxygen</td>
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<tr>
<td>Water</td>
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<td>2.5219</td>
<td>6613.8679</td>
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<td>CO2</td>
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<td>2.5219</td>
<td>2.8243E+05</td>
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<tr>
<td>Methane</td>
<td>3.1472E-02</td>
<td>3.1472E-02</td>
<td>9476.0785</td>
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<tr>
<td>Ethane</td>
<td>6.2314</td>
<td>6.2314</td>
<td>1.9802</td>
</tr>
</tbody>
</table>

**Total Flow:**
- LB mol/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:**

### Phase: Liquid

**Components:**
- Propane: 2041.7827
- Propene: 4571.7475
- Hydrogen: 6.6252E-05
- Oxygen: 0.0
- Water: 0.0
- CO: 5.5859E-04
- CO2: 5.7303E-02
- Methane: 1.9617E-03
- Ethane: 0.2072
- Ethene: 7.0584E-02

**Components:**
- Propane: 9.0036E+04
- Propene: 1.9238E+05
- Hydrogen: 1.3364E-04
- Oxygen: 0.0
- Water: 0.0
- CO: 1.5646E-02
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
PRESS PSIA  575.0000
VFRAC  0.0
LFRC  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/CUFT  0.6934
LB/CUFT  29.6089

AVG MW  42.7024

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F  105.9465
PRESS PSIA  575.0000
HFLUX BTU/HR  -8.5898+07

STREAM ID  S305
FROM:  N301
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
ETHANE 1.9802

TOTAL FLOW:
LBMOL/HR 6613.8679
LB/HR 2.8243e+05
CUFT/HR 9619.8001

STATE VARIABLES:
TEMP F 109.6769
PRES PSIA 575.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
BTU/LBMOL -1.2836e+04
BTU/LB -300.6006
BTU/HR -8.4898e+07

ENTROPY:
BTU/LBMOL-R -56.3604
BTU/LB-R -1.3198

DENSITY:
LBMOL/CUFT 0.6875
LB/CUFT 29.3591

AVG MW 42.7024

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 109.6769
PRES PSIA 575.0000
HFLX BTU/HR -8.4898e+07

S306

FROM : M301
TO : M501

SUBSTREAM: MIXED PHASE:
COMPONENTS: LBMOL/HR
PROPANE 2041.7827
PROPENE 4571.7475
HYDROGEN 6.6292e-05
OXYGEN 0.0
WATER 0.0
CO 5.5859e-04
CO2 5.7903e-02
METHANE 1.9617e-03
ETHANE 0.2072
ETHERE 7.0564e-02

COMPONENTS: LB/HR
PROPANE 9.0036e+04
PROPENE 1.9238e+05
HYDROGEN 1.3364e-04
OXYGEN 0.0
WATER 0.0
CO 1.5646e-02
CO2 2.5219
METHANE 3.1472e-02
ETHANE 6.2314
ETHERE 1.9802

TOTAL FLOW:
LBMOL/HR 6613.8679
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<tr>
<td>TEMP F</td>
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<tr>
<td>PRES PSIA</td>
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<td>AVG Mw</td>
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MIXED SUBSTREAM PROPERTIES:

### ALL PHASES

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<tbody>
<tr>
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<tr>
<td>PRES PSIA</td>
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<td>HFLNX BTU/HR</td>
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STREAM ID: s307
FROM: M801
TO: C302

SUBSTREAM: MIXED

PHASE: VAPOR

COMPONENTS: LBMOL/HR

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<tr>
<td>PROPENE</td>
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<td>ETHANE</td>
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<tr>
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COMPONENTS: LB/HR

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TOTAL FLOW:

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<td>CUFT/HR</td>
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STATE VARIABLES: 
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<tbody>
<tr>
<td>PRES</td>
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<tr>
<td>VFRAC</td>
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<td>AVG MW</td>
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**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: LB MOL/HR**

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<thead>
<tr>
<th>COMPOUND</th>
<th>LB MOL/HR</th>
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<tbody>
<tr>
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<tr>
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**COMPONENTS: LB HR**

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<td>WATER</td>
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</tr>
<tr>
<td>CO</td>
<td>0.0</td>
</tr>
<tr>
<td>CO2</td>
<td>0.0</td>
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<tr>
<td>METHANE</td>
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<td>ETHANE</td>
<td>0.0</td>
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<tr>
<td>ETHENE</td>
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**TOTAL FLOW:**

<table>
<thead>
<tr>
<th>FLOW</th>
<th>VALUE</th>
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<tbody>
<tr>
<td>LB MOL/HR</td>
<td>4207.6164</td>
</tr>
<tr>
<td>LB HR</td>
<td>1.7710e+05</td>
</tr>
<tr>
<td>CUFT/HR</td>
<td>1.2493e+06</td>
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**STATE VARIABLES:**

<table>
<thead>
<tr>
<th>TEMP</th>
<th>F</th>
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<tbody>
<tr>
<td>PRES</td>
<td>PSIA</td>
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<tr>
<td>VFRAC</td>
<td>1.0000</td>
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</table>

Page 46
LFRAC  0.0
SFRC  0.0

ENTHALPY:
BTU/LBmol  8689.9830
BTU/LB  206.4584
BTU/HR  3.6564+07

ENTROPY:
BTU/LBmol-R  -34.1963
BTU/LB-R  -0.8124

DENSITY:
LBmol/cuft  3.3680-03
LB/cuft  0.1148

AVG Mw  42.0907

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP  F  93.6757
PRES  PSIA  20.0000
HFLMIX  BTU/HR  3.6564+07

5309
----

STREAM ID  5309
FROM  C303
TO  HK301

SUBSTREAM: MIXED
PHASE:  VAPOUR

COMPONENTS: LBmol/hr
PROPANE  21.0380
PROPENE  4185.5784
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+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  1.7710+05
CUFT/HR  1.4412+05

STATE VARIABLES:
TEMP  F  338.2659
PRES  PSIA  250.0000
VFRAC  1.0000
LFRAC  0.0
SFRC  0.0

ENTHALPY:
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<td>BTU/HR</td>
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<tr>
<td>BTU/LB-R</td>
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<tr>
<td>LBMOL/CUFT</td>
<td>2.9195e-02</td>
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<tr>
<td>LB/CUFT</td>
<td>1.2289</td>
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<td>AVG MW</td>
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**MIXED SUBSTREAM PROPERTIES:**

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<tr>
<td>HFLMX BTU/HR</td>
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**STREAM ID:** S310  
**FROM:** M801  
**TO:** C301  

**SUBSTREAM: MIXED PHASE:** VAPOR  
**COMPONENTS: LBMOL/HR**  
- PROPANE: 2020.7447  
- PROPENE: 385.1691  
- HYDROGEN: 6.6292e-05  
- OXYGEN: 0.0  
- WATER: 0.0  
- CO: 5.5859e-04  
- CO2: 5.7303e-02  
- METHANE: 1.9617e-03  
- ETHANE: 0.2072  
- ETHENE: 7.0584e-02  

**COMPONENTS: LB/HR**  
- PROPANE: 8.9108e+04  
- PROPENE: 1.6208e+04  
- HYDROGEN: 1.3364e-04  
- OXYGEN: 0.0  
- WATER: 0.0  
- CO: 1.6646e-02  
- CO2: 2.5219  
- METHANE: 3.1472e-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
### ENTROPY:
- **BTU/LBML-3**  
  -60.2607
- **BTU/LB-3**  
  -1.3767

### DENSITY:
- **LBML/CUFT**  
  7.4764-02
- **LB/CUFT**  
  3.2726
- **AVG Mn**  
  43.7721

### MIXED SUBSTREAM PROPERTIES:

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<td>HFLMX BTU/HR</td>
<td>-7.9172+07</td>
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**S311**

**STREAM ID**       **S311**
**FROM**             **C301**
**TO**               **M3X01**

**SUBSTREAM: MIXED**

**PHASE**  
**COMPONENTS: LBML/HR**  
PROPAKE  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**  
PROPAKE  8.9108+04
PROPENE  1.6208+04
HYDROGEN  1.3364-04
OXYGEN  0.0
WATER  0.0
CO  1.5646-02
CO2  2.5213
METHANE  3.1472-02
ETHANE  6.2314
ETHENE  1.9802

**TOTAL FLOW:**  
- **LBML/HR**  
  2406.2515
- **LB/HR**  
  1.0533+05
- **CUFT/HR**  
  7.3548+05

**STATE VARIABLES:**  
- **TEMP**  
  109.9772
- **PRES**  
  20.0000
- **VFRAC**  
  1.0000
- **LFRAC**  
  0.0
- **SFRA**  
  0.0

**ENTHALPY:**  
- **BTU/LBML**  
  3.5827+04
- **BTU/LB**  
  -818.4816
- **BTU/HR**  
  -8.6208+07

**ENTROPY:**  
- **BTU/LBML-3**  
  58.1411
- **BTU/LB-3**  
  -1.3283

---

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DENSITY:
  LB/MOL/CUFT  3.2717-03
  LB/CUFT  0.1432
  AVG Mw  43.7721

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***

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<tbody>
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<tr>
<td>PRES</td>
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<tr>
<td>HFLX</td>
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</tbody>
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S312

-----

STREAM ID  S312
FROM       MX301
TO         B1

SUBSTREAM: MIXED

PHASE: MIXED

COMPONENTS: LB/MOL/CUFT

<table>
<thead>
<tr>
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<td>PROPANE</td>
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<tr>
<td>PROPENE</td>
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<td>HYDROGEN</td>
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<td>OXYGEN</td>
<td>0.0</td>
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<tr>
<td>WATER</td>
<td>21.6101</td>
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<td>5.5859-04</td>
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<td>CO2</td>
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<td>METHANE</td>
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<tr>
<td>ETHANE</td>
<td>0.2072</td>
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<td>ETHENE</td>
<td>7.0584-02</td>
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COMPONENTS: LB/HR

<table>
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<tr>
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<tbody>
<tr>
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<tr>
<td>PROPENE</td>
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<td>OXYGEN</td>
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<td>WATER</td>
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<td>CO</td>
<td>1.5646-02</td>
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<td>CO2</td>
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<tr>
<td>METHANE</td>
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<tr>
<td>ETHANE</td>
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<td>ETHENE</td>
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TOTAL FLOW:

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<tr>
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<th>LB/HR</th>
<th>CUFT/HR</th>
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<tbody>
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STATE VARIABLES:

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<td>LFRAC</td>
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ENTHALPY:

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<tr>
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<tr>
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<td>BTU/LB</td>
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<td>BTU/HR</td>
<td>-2.2800+08</td>
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ENTROPY:

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<th>LB/CUFT</th>
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<tr>
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**AVG MW**: 43.8358

**MIXED SUBSTREAM PROPERTIES:**

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<tbody>
<tr>
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<td><strong>TO</strong> :</td>
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**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**: 1.6138-05
- **PROPENE**: 1.5002-04
- **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**: 2.0674-05
- **CUFT/HR**: 1.3445-06

**STATE VARIABLES:**
- **TEMP F**: 71.6000
- **PRES PSIA**: 20.0000
- **VFRAC**: 1.0000
- **LFRAC**: 0.0
- **SRFRAC**: 0.0

**ENTHALPY:**
- **BTU/LB/MOL**: -4.1282-04
- **BTU/LB**: -941.7967
- **BTU/HR**: -1.9470-08

**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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**SUBSTREAM: MIXED**

**PHASE:** VAPOR

**COMPONENTS: LBMOL/HR**

- **PROPANE:** 4340.0723
- **PROPENE:** 356.5097
- **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:**

- **LBMOL/HR:** 4716.3350
- **LB/HR:** 2.0674E+05
- **CUFT/HR:** 4.4694E+05

**STATE VARIABLES:**

- **TEMP F:** 180.7066
- **PRES PSIA:** 72.5189
- **VFRAC:** 1.0000
- **LFRAC:** 0.0
- **SFRAc:** 0.0

**ENTHALPY:**

- **BTU/LBMOL:** -3.9253E+04
- **BTU/LB:** -895.4494
- **BTU/HR:** -1.8513E+08

**ENTROPY:**

- **BTU/LBMOL-R:** -61.0957
- **BTU/LB-R:** -1.3937

**DENSITY:**

- **LBMOL/CUFT:** 1.0553E-02
- **LB/CUFT:** 0.4626

**AVG MW:** 43.8358

**MIXED SUBSTREAM PROPERTIES:**

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</table>

Page 52
STREAM ID: S315
FROM: HX301
TO: H802

SUBSTREAM: MIXED
PHASE: VAPOR

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
CFUFT/HR 1.4203E+05

STATE VARIABLES:
TEMP F 326.7204
PRESS PSIA 250.0000
VFRAC 1.0000
LFRAC 0.0
SFRACT 0.0

ENTROPY:
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/CFUFT 2.9624E-02
LB/CFUFT 1.2469
AVG MW 42.0907

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP F 326.7204
PRESS 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+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  5849.6963

STATE VARIABLES:
TEMP   F  100.0000
PRES  PSIA  250.0000
VFRAC  0.0
SFRAC  1.0000

ENTHALPY:
BTU/LB/MOL  3161.5962
BTU/LB  75.1139
BTU/HR  1.3303+07

ENTROPY:
BTU/LB/MOL-R  -48.9159
BTU/LB-R  -1.1622

DENSITY:
LB/CUFT  0.7193
LB/CUFT  30.2753

MIXED SUBSTREAM PROPERTIES:

*** ALL PHASES ***
TEMP   F  100.0000
PRES  PSIA  250.0000
HFLMX  BTU/HR  1.3303+07

Page 54
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers
Product name: 2-Methylimidazole
Product Number: M90650
Brand: Aldrich
CAS-No.: 88-9-1

1.2 Relevant identified uses of the substance or mixture and uses advised against
Identified uses: Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet
Company: Sigma-Aldrich
3050 Spruce Street
SAIN'T LOUIS MO 63103
USA
Telephone: +1 800-325-5333
Fax: +1 800-325-5062

1.4 Emergency telephone number
Emergency Phone #: (314) 776-5555

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
Pictogram
Signal word: Danger
Hazard statement(s): Harmful if inhaled. Harmful if swallowed.
H302. H314
Precautionary statement(s): P280 Do not breathe dust or mist.
P254 Wash skin thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.
P260 Wear protective gloves/protective clothing/eye protection/face protection.
P301 + P312 IF SWALLOWED: Call a POISON CENTER or doctor/physician if you feel unwell.
P302 + P320 + P331 IF INGESTED: Rinse mouth. Do NOT induce vomiting.
P303 + P361 + P333 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 If skin contact: Immediately call a POISON CENTER or doctor/physician.
P311 If eye contact: Specific treatment (see supplemental first aid instructions on this label).
P303 Wash contaminated clothing before reuse.
P406 Store locked up.
P501 Dispose of content/container to an approved waste disposal plant.

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

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances
Synonyms: 2-Methylpyrazine
Formula: C₆H₈N₂
Molecular Weight: 110.14 g/mol
CAS-No.: 88-9-1
EC-No.: 217-767-7

Hazardous components
Component Classification Concentration
2-Methylimidazole Acute Tox. 4, Skin Corr. 1A, H302, H314 90 - 103 %
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: Contact 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 pain is relieved.
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 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.

Aldrich - M90650
5.2 Special hazards arising from the substance or mixture
Carbon oxides, nitrogen oxides (NOx)

5.3 Advice for first aiders
When self-contained breathing apparatus for the fighting if necessary.

5.4 Further information
no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid skin contact. 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. Inhibit 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 substance 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 ANSI Z87.1 (US) or EN 166 (EU).

Skin protection
Handle with gloved. 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
Thickens through time: 480 mm

Material tested: Dermatex® (KCL 740 / Adhesive Z577272, Size M)

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

Material tested: Dermatex® (KCL 740 / Adhesive Z577272, Size M)

Data source: KCL GmbH, D-35124 Eschenfeld, phone +49 (0)6559-8700, e-mail: sales@kcl.de, test method: EN374.

If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete and 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
When 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 listed and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

- Appearance: Form: powder
- Odour: no data available
- Odour Threshold: no data available
- pH: no data available
- Melting point/boiling point: Melting point: 142 - 143°C (285 - 289°F); bt.
- Flash point: no data available
- Evaporation rate: no data available
- Flameability (solid/gas): no data available
- Upper/lower explosive limits: no data available
- Vapour pressure: no data available
- Vapour density: no data available
- Relative density: no data available
- Water solubility: no data available
- Partition coefficient n-octanol/water: no data available
- Auto-ignition temperature: no data available
- Decomposition temperature: no data available
no data available
Specific target organ toxicity - single exposure
no data available
Specific target organ toxicity - repeated exposure
no data available
Aspiration hazard
no data available
Additional information
RTCS: NI175000
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1. Toxicity
Toxicity to fish
LC50 - Pimephales promelas (fathead minnow): 230 mg/l - 96 h

12.2. Persistence and degradability
no data available

12.3. Bioaccumulative potential
no data available

12.4. Mobility in soil
no data available

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

12.6. Other adverse effects
no data available

13. DISPOSAL CONSIDERATIONS

13.1. Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dilute or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as a hazardous waste.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 3059
Class: 9
Packing group: II
Proper shipping name: Polyamines, solid, corrosive n.o.s. (2-Methylimidazole)
Flashpoint: 54°C
Fusion Inflammable: No

IMO
UN number: 3059
Class: 9
Packing group: II
Proper shipping name: POLYAMINES, SOLID, CORROSIVE, N.O.S. (2-Methylimidazole)
Flashpoint: 54°C
Fusion Inflammable: No

IATA
UN number: 3059
Class: 9
Packing group: II
Proper shipping name: Polyamines, solid, corrosive n.o.s. (2-Methylimidazole)
Flashpoint: 54°C
Fusion Inflammable: No

i) Viscosity
no data available
ii) Explosive properties
no data available
iii) Oxidizing properties
no data available

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
no data available

10.5. Incompatible materials
Strong oxidizing agents, acids, Acid chlorides, Acid anhydrides

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

11. TOXICOLOGICAL INFORMATION

11.1. Information on toxicological effects

Acute toxicity
LD50 Oral - mouse: 1,400 mg/kg
R painting: Behavioral Convulsions or effect on seizure threshold.
Inhalation: no data available
Dermal: no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Genetic cell mutagenicity
no data available

Carcinogenicity
IARC: 2B - Group 2B: Possibly carcinogenic to humans (2-Methylimidazole)

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

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or potential 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
Activated Safety Data Sheet

Activated Carbon

Section 01 - Chemical and Product and Company Information

Product Identifier: Activated carbon (All Grades)

Product Use: Water purification, gold recovery, and air scrubbing

Supplier Name: Clevetech Industries Inc.
1302 Quaker Avenue
Saskatoon, SK Canada

Prepared By: Clevetech Industries Inc., Technical Department
Phone: 1 (800) 387-7503
Prepared By: Clevetech Industries Inc. Technical Department
Preparation Date: February 10, 2000

Emergency Phone: 1 (800) 387-7503

Section 02 - Composition / Information on Ingredients

Hazardous Ingredients: Activated Carbon

CAS Number: Activated Carbon 7440-44-0

Synonym (s): Activated granular carbon, activated powdered carbon, pelletized activated carbon, activated charcoal, animal bone black.

Section 03 - Hazard Identification

Inhalation: Non-toxic through ingestion
Skin Contact / Absorption: Not Available
Eye Contact: Mechanical dust irritation

Exposure Limits: OSHA PEL: 50 mg/m³ as resp.
ACGIH TLV: 100 mg/m³ as total

Section 04 - First-Aid Measures

Inhalation: Remove to fresh air.
Skin Contact: Wash skin thoroughly with soap and water.
Eye Contact: Flush eyes with大量水.

Section 05 - Fire-Fighting Measures

Flammability: Non-flammable.
Reactivity: Reactivity Hazard: 0

Section 06 - Accidental Release Measures

Spill Containment: Absorb and continue the collection of spill.

Section 07 - Handling and Storage

Physical Hazards: None.
Chemical Hazards: None.

Section 08 - Exposure Controls / Personal Protection

Respiratory Protection: None.
Eye Protection: Not required.
Skin Protection: None.

Section 09 - Physical and Chemical Properties

Appearance: Black.

Section 10 - Stability and Reactions

Stability: Stable.

Section 11 - Toxicological Information

Acute Toxicity: Skin irritation.

Section 12 - Ecological Information

Disposal: Disposal must be in accordance with Federal, State, and Local Regulations. Before disposal, consult with local authorities regarding disposal.

Section 13 - Disposal Considerations

Hazardous Waste: None.

Section 14 - Transport Information

UN Number: 3952

Section 15 - Regulatory Information

SARA 302 Components
SARA 302: Not applicable.

SARA 313 Components
SARA 313: Not applicable.

Massachusetts Right-To-Know Components
No components subject to Massachusetts Right-To-Know Act.

Pennsylvania Right-To-Know Components

New Jersey Right-To-Know Components

California Prop. 65 Components

WARNING: This product contains a chemical known to the State of California to cause cancer.

Further Information

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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 cool, 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 taken (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 ......................................... Body suits, aprons, and/or coveralls of chemical-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.

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 .................................. 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. Forbids hold 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-combustible under normal circumstances. Once ignited, the fire generally burns slowly (smolder) 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, ammonia, and carbon dioxide. Contact with strong oxidizers (ozone). Most copper 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: Not likely to occur.

Section 11 - Toxicological Information

Irritancy: Not Available
Sensitization: Not Available
Chronic/Acute Effects: Not Available
Synergistic Materials: Not Available
Animal Toxicity Data: 
LD_{50}(oral, rat) > 15g/kg
LD_{50}(intravital, rat) > 64.4mg/kg
Carcinogenicity: Not considered to be carcinogenic as per IARC, NTP, and GSHIA.
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, odorless, particulate solid, pellet or powder

Odor Threshold: Not Applicable

Specific Gravity (Water = 1): 0.25 - 0.80

Vapor Pressure (mm Hg, 30°C): Not Applicable

Vapor Density (Air = 1): Not Applicable

Evaporation Rate: Not Applicable

Boiling Point: Maximum 400°C

Freeze/Melting Point: > 305°C

pH: Not Applicable

Water/Oil Distribution Coefficient: Not Applicable

Bulk Density: > 603g/L

% Volatiles by Volume: 0%

Solubility in Water: Insoluble

Molecular Formula: C

Molecular Weight: 12.011

Engineering Controls

Ventilation Requirements: Mechanical ventilation (dilution or local exhaust), process or personnel enclosure and control of process conditions should be provided. Supply sufficient replacement air to make up for air removed by exhaust systems.

Other: Emergency shower and eyewash should be in close proximity.
Section 13 - Disposal Considerations

Waste Disposal: Dispose in accordance with all federal, provincial, and/or local regulations including the Canadian Environmental Protection Act.

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.

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 THOSE REGULATIONS.

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 instruct 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: Receiver of the chemical goods / MSDS coordinator

As part of our commitment to the Canadian Association of Chemical Distributors (CACD) Responsible Distribution® initiative, ClearTech Industries Inc. and its associated companies require, as a condition of sale, that you forward the attached Material Safety Data Sheet(s) 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.
SYMPTOMS: Headache, sweating, rapid breathing, increased heartbeat, shortness of breath, dizziness, mental depression, visual disturbances, and shakiness.

CHRONIC EFFECTS: None established.

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None

CARCINOGENICITY: Carbon dioxide is not listed by NTP, OSHA or IARC.

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 antidote. 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 the area or cool with water. Self-contained breathing apparatus (SCBA) may be required for rescue workers.

UNUSUAL HAZARDS: Upon exposure to intense heat or flame, cylinder will vent rapidly and may 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 concentration. 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 7. 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

MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: Carbon Dioxide

CHEMICAL NAME: Carbon Dioxide

FORMULA: CO₂

SYNONYM: Carbonic Anhydride, Carbonic Acid Gas, Carbon Anhydride

MANUFACTURER: Air Products and Chemicals, Inc.

7221 Hamilton Boulevard
Allentown, PA 18195-1501

PRODUCT INFORMATION: TWA = 500 ppm

OSHA: PEL-TWA = 5000 ppm

ACGIH: TLV-TWA = 5000 ppm

MDL NUMBER: 1005

REVISION DATE: March 1993

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

CONCENTRATION: Carbon dioxide is sold as pure product > 99%.

CAS NUMBER: 124-38-0

SECTION 3. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Carbon dioxide is a nonflammable liquefied compressed gas packaged in cylinders under its own vapor pressure of 638 psig at 70°F (21.1°C). High concentrations can cause rapid suffocation 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

800-531-9374 Continenal U.S., Canada, or Puerto Rico
610-481-7711 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 ORGAN: Central nervous system

EFFECT: Asphyxiation (suffocation). Overexposure may cause damage to retinal ganglion cells and central nervous system.
SECTION 10. STABILITY AND REACTIVITY

STABILITY: Stable
CONDITIONS TO AVOID: None
INCOMPATIBILITIES (Materials to Avoid): None

REACTIVITY:
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:

CONCENTRATION EFFECT
1% Slight increase in breathing rate
2% Breathing rate increases to 50% above normal. Prolonged exposure can cause headache and lightheadedness.
3% Breathing increases to twice the normal rate and becomes labored. Weak narcotic effect. Impaired hearing, headache, increase in blood pressure and pulse rate.
4-5% Breathing increases to approximately four times the normal rate, symptoms of intoxication become evident and slight shaking may be felt.
5-10% Characteristic sharp odor noticeable. Very labored breathing, headache, visual impairment and ringing in the ears. Judgement may be impaired, followed within minutes by loss of consciousness.
50-100% Unconsciousness occurs more rapidly above 10% level. Prolonged exposure to high concentrations may eventually result in death from asphyxiation.

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 reinvented, and valve protection cap is secured before shipping cylinder.

WASTE DISPOSAL 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 heating with a mild blowtorch.

SECTION 14. TRANSPORT INFORMATION

DOT SHIPMENT 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 discontinues 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 overtightened or rusted caps.

Only the proper CO2 connections should be used, never use adapters. Use piping and equipment adequately designed to withstand pressures to be encountered. If liquid product is being used, ensure steps have been taken to prevent entrainment of liquid in closed systems. The use of pressure relief devices may be necessary. Use a check valve or other protective apparatus in an line or piping 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 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. (CGA) 703-979-0000) pamphlet CGA P-1. Safe Handling of Compressed Gases in Containers. Local regulations 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 fatal 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): 0.0144 lb/ft³ (1.532 kg/m³)

VAPOR PRESSURE (at 70°F [21.1°C]): 838 psig

SPECIFIC GRAVITY (at 25°C): 1.523

SPECIFIC VOLUME (at 70°F [21.1°C] and 1 atm): 8.74 ft³/1b (0.5457 m³/kg)

BOILING POINT: -106.9°F [-76.5°C]

TRIPLE POINT (at 6.86 psig): -110.8°F [-76.8°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 oxide (CO)
- CO: Exhause gas; Flux gas; Carbonic oxide; Carbon oxide;
- Carbon monoxide (CO)
- Carbon oxixide (CO)
- Carbon monoxide (CO)
- Carbon monoxide (CO)
- Carbon monoxide (CO)

Product use:
- Synthesis/Analytical chemistry

Synonym:
- Carbon dioxide (CO)
- CO: Exhause gas; Flux gas; Carbonic oxide; Carbon oxide;
- Carbon monoxide (CO)
- Carbon oxixide (CO)
- Carbon monoxide (CO)
- Carbon monoxide (CO)
- Carbon monoxide (CO)

Supplier’s details:
- Airgas USA, LLC and its affiliates
- 220 North Radnor-Chester Road, Suite 100
- Radnor, PA 19087-5283
- 1-800-734-3433

Emergency telephone number (24 hours of operation):
- 1-800-734-3433

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 3
- Toxic to reproduction (Fertility) - Category 1
- Toxic to reproduction (Female) - Category 1
- Specific target organ toxicity (Repeated exposure) - Category 1

GHS labeling elements:
- Hazard pictograms:

Signal word:
- Danger

Hazard statements:
- Extremely flammable gas
- May form explosive mixtures with air;
- Contains gas under pressure; may explode if heated;
- Asphyxiating even with adequate oxygen;
- May cause asphyxiation;
- May damage test or the unborn child;
- Causes damage to organs through prolonged or repeated exposure.

Precautionary statements:

Date of issue/Date of revision:
- 1/3/2015

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 (RQs) 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 and 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
- Section 301/311: Requires submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification of EPA defined hazardous classes. The hazard classes for this product are:
  - Immediate Health: Yes
  - Pressure: Yes
  - Delayed Health: No
  - Reactivity: No
  - Flammability: 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.
  - SCAG/D0: VOC = not applicable

Page 5 of 5

HGC #: 108
Page #: 5/13/19
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 fosinoprilate is still present, the rescuer should wear appropriate mask or self-contained breathing apparatus. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth respiratory assistance. Wash contaminated clothing thoroughly with water before removing it. Continue to rinse for at least 10 minutes. Get medical attention.

Skin contact: Wash contaminated skin with plenty of water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, wear contaminated clothing thoroughly with water before removing it. Continue to rinse for at least 10 minutes. Get medical attention. Wash clothing before reuse. Clean shoes thoroughly before reuse.

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

Most important symptoms/effects, acute and delayed

Potential acute health effects

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

Inhalation: Toxic if inhaled.

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

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

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

Over-exposure signs/symptoms

Eye contact: No specific data.

Inhalation: Adverse symptoms may include the following: reduced fetal weight, increased fetal deaths, skeletal malformations.

Skin contact: Adverse symptoms may include the following: reduced fetal weight, increased fetal deaths, skeletal malformations.

Ingestion: Adverse symptoms may include the following: reduced fetal weight, increased fetal deaths, skeletal malformations.

Section 2. Hazards identification

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

Prevention: Never put cylinders into unventilated areas of passenger vehicles. Obtain special instructions before use. Do not handle until all safety precautions have been read and understood. Use personal protective equipment as required. Keep away from heat, sparks, open flames and hot surfaces. No smoking. Use only outdoors or in a well-ventilated area. Do not breathe gas. Do not eat, drink or smoke when using this product. Wash hands thoroughly after handling. Use and store only cylinders in a well-ventilated place.

Response: Get medical attention if you feel unwell. If exposed or suspected of being exposed, get medical attention. If inhaling: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or physician. Leaking gas: Do not extinguish, unless it can be stopped safely. Eliminate all ignition sources if safe to do so.

Storage: Store locked up. Protect from sunlight. Protect from sunlight when ambient temperature exceeds 50°C (122°F). Store in a well-ventilated place.

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

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

Section 3. Composition/information on ingredients

Substance/mixture: Substance

Chemical name: Carbon monoxide

Other means of identification: Carbon monoxide (CAS 630-08-0), Carbon monoxide (CAS 006-88-3), Carbon monoxide (CAS 7440-19-9), Carbon monoxide (CAS 630-08-0), Carbon monoxide (CAS 006-88-3), Carbon monoxide (CAS 7440-19-9)

CAS number/other identifiers: 630-08-0

Product code: 630-08-0

Ingredient name: % CAS number

Carbon monoxide: 100 630-08-0

There are no additional ingredients present which, within the current knowledge of the supplier and 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

Description of necessary first aid measures

Eye contact: Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention.
Section 7. Handling and storage

Precautions for safe handling

Protective measures: Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid exposure - retain special instructions before use. Avoid exposure during pregnancy. Do not handle until all safety precautions have been read and understood. Do not get in eyes or on skin or clothing. Do not breathe gas. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Store and use away from heat, sparks, open flames or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. Use only non-sparking tools. Empty containers retain product residue and can be hazardous. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage. Do not drop, roll, slide, or drag. Use a suitable hand truck for cylinder movement.

Advice on general occupational hygiene: Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Work areas should be well ventilated and free from smoking. Prevent ingestion and exposure to skin. Keep container tightly closed and sealed until ready for use. Cylinders should be stored upright, with valve protection caps in place, and firmly secured to prevent tripping or being knocked over. Cylinder temperatures should not exceed 52°C (125°F).

Conditions for safe storage, including any incompatibilities: Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Store leak-proof. Eliminate all ignition sources. Keep container tightly closed and sealed until ready for use. Cylinders should be stored upright, with valve protection caps in place, and firmly secured to prevent tripping or being knocked over. Cylinder temperatures should not exceed 52°C (125°F).

Section 8. Exposure controls/personal protection

Control parameters: Occupational exposure limits

<table>
<thead>
<tr>
<th>Ingredient name</th>
<th>Exposure limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon monoxide</td>
<td>ACGIH TLV (United States, 3/9/13), TWA: 20 mg/m³ 8 hours. TWA: 25 ppm. 8 hours. Models REA (United States, 9/2013). CEC, 229 mg/m³. CEC, 250 mg/m³. CEC, 320 mg/m³. TWA: 40 mg/m³ 10 hours. TWA: 25 ppm. 10 hours. OSHA PEL (United States, 6/2016). TWA: 50 mg/m³ 8 hours. TWA: 50 ppm 8 hours. OSHA PEL (United States, 3/1989). CEC, 229 mg/m³. CEC, 250 mg/m³. TWA: 40 mg/m³ 10 hours. TWA: 25 ppm 8 hours.</td>
</tr>
</tbody>
</table>

Appropriate engineering controls: Use only with adequate ventilation. Use process enclosure, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapor or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Date of issuance: 5/12/2015 Date of previous issue: 5/12/2015 Version: 0.07 5/12

Section 5. Fire-fighting measures

Extinguishing media: Use an extinguishing agent suitable for the surrounding fire. Suitable extinguishing media: none known. Unsuitable extinguishing media: none known. Specific hazards arising from the chemical: Contains gas under pressure. Extremely flammable gas. In a fire or if heated, a pressure increase will occur and the container may burst, with the risk of a subsequent explosion. Hazardous thermal decomposition products: Includes the following materials: carbon dioxide, carbon monoxide. Special protective actions for firefighters: Promptly isolate the scene by removing all persons from the vicinity of the incident. If there is a fire, no action shall be taken involving any personnel risk or without suitable training. Contact supplier immediately for specialist advice. Avoid containers from the area if this can be done without risk. Use water spray to keep fire-exposed containers cool. If it is necessary to move the fire, ensure that it can be done without risk. In this case, it is necessary to ensure that the fire is completely extinguished before it is moved. Special protective equipment for firefighters: Firefighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a facepiece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures:

For non-emergency personnel: Accidental releases pose a serious fire or explosion hazard. No action shall be taken involving any personnel risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Shut off all ignition sources. No flares, smoking or flames in hazard area. Do not breathe gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

For emergency responders: If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel."

Environmental precautions: Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. In the event of the gas being released, call the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up:

Small spill: Immediately contact emergency personnel. Stop leak if without risk. Use appropriate forms and equipment. Large spill: Immediately contact emergency personnel. Stop leak if without risk. Use appropriate forms and equipment. Note: see Section 2 for emergency contact information and Section 13 for waste disposal.

Date of issuance: 5/12/2015 Date of previous issue: 5/12/2015 Version: 0.07 5/12
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 explosives limits (flammable limits) : 
Upper: 74.2%, Lower: 13.9%
Vapor pressure : Not available.
Specific Volume (g/lh) : 13.8593
Density (g/cm3) : 0.072
Relative density : Not applicable.
Solubility in water : Not available.
Partition coefficient: n-octanol/water : Not available.
Auto-ignition temperature : 657°C (1214.6°F)
Decomposition temperature : Not available.
SADY : 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.
Possible 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 penetrate, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition.
Incompatibility with other substances : Extremely reactive or incompatible with the following materials: assisting 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
Result : LC50 Inhalation Gas
Route : Rat
Dose : 3760 ppm
Exposure : 1 hours

Section 8. Exposure controls/personal protection

Environmental exposure controls : 
- Personal protective equipment (PPE) 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.

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.
- Protective clothing : Appropriate techniques should be used to remove potentially contaminated clothing.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary.

Skin protection
- Hand protection : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products.

Other skin protection : Not applicable.

Respiratory protection : Not applicable.

Section 9. Physical and chemical properties

Appearance : Gas. [MAY BE A LIQUID AT LOW TEMPERATURE OR HIGH PRESSURE.]
Color : Colorless.
Molecular weight : 27.01 g/mole
Molecular formula : CO
Boiling point : -191.52°C (-312.7°F)
Melting point : -211.6°C (-348.9°F)
Critical temperature : -140.15°C (-223.3°F)
Odor : Odorless.
Odor threshold : Not available.
PH : Not available.
Flash point : Not available.
Ignition temperature : Not applicable.

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Section 11. Toxicological information

Potential immediate effects
Not available.

Potential delayed effects
Not available.

Long-term exposure
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 minimized wherever 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 regional locar authority requirements. Dispose of surplus and non-reclaimable products via a licensed waste disposal contractor. Waste should not be disposed of overhead to the sewer access to comply with the requirements of all authorities with jurisdiction. Empty Argos-owned pressure vessels should be returned to Arigo. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not possible.

Date of issue/Date of revision: 3/12/2015 3/12/2015 Version: 0.07
### Section 15. Regulatory information

**Clean Air Act Section 602**
- Not listed

**Class II Substances**
- Not listed

**DEA List III Chemicals (Precursor Chemicals)**
- Not listed

**DEA List III Chemicals (Essential Chemicals)**
- Not listed

**SARA 302/304**
- Not applicable

**SARA 311/312**
- Fire hazard
- Sudden release of pressure
- Immediate (acute) health hazard
- Delayed (chronic) health hazard

**Composition/Information on ingredients**

<table>
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<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>
</tr>
</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**: Not applicable.
- **New Jersey**: Not applicable.
- **Pennsylvania**: Not applicable.
- **California Prop 65**: WARNING: This product contains a chemical known to the State of California to cause birth defects or other reproductive harm.

**Ingredient name**

- **Carcinogen**: Not significant risk level
- **Reproductive**: No significant risk level
- **Maximum acceptable dosage level**: Not determined

**Canada inventory**
- This material is listed or exempted.

**International regulations**

- **Australia Inventory (AICS)**: This material is listed or exempted.
- **China inventory (ECSC)**: This material is listed or exempted.
- **Japan inventory**: This material is listed or exempted.
- **Korea inventory**: This material is listed or exempted.
- **New Zealand Inventory of Chemicals (NZIC)**: This material is listed or exempted.
- **Philippines Inventory (PICCS)**: This material is listed or exempted.
- **Taiwan inventory (CSNI)**: Not determined.

**Chemical Weapons Convention List Schedule I Chemicals**
- Not listed

**Date of issue/Date of revision**: 2/4/2015

### Section 13. Disposal considerations

Not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

### Section 14. Transport information

**DOT**
- UN number: UN1018
- UN proper shipping name: Carbon monoxide, compressed
- UN hazard class(es): 2.3 (2) (1)
- Packing group: -
- Specific precautions: -
- Additional information: 
  - United States Inventory:
    - Code: CSNI
    - Chemical or physical hazard:
      - Class I: None
      - Class II: None
      - Class III: None
  - Not applicable: -

**TDG**
- UN number: UN1018
- UN proper shipping name: Carbon monoxide, compressed
- UN hazard class(es): 2.3 (2) (1)
- Packing group: -
- Specific precautions: -
- Additional information: 
  - United States Inventory:
    - Code: CSNI
    - Chemical or physical hazard:
      - Class I: None
      - Class II: None
      - Class III: None
  - Not applicable: -

**Mexico**
- UN number: UN1018
- UN proper shipping name: Carbon monoxide, compressed
- UN hazard class(es): 2.3 (2) (1)
- Packing group: -
- Specific precautions: -
- Additional information: 
  - United States Inventory:
    - Code: CSNI
    - Chemical or physical hazard:
      - Class I: None
      - Class II: None
      - Class III: None
  - Not applicable: -

**IMO**
- UN number: UN1018
- UN proper shipping name: Carbon monoxide, compressed
- UN hazard class(es): 2.3 (2) (1)
- Packing group: -
- Specific precautions: -
- Additional information: 
  - United States Inventory:
    - Code: CSNI
    - Chemical or physical hazard:
      - Class I: None
      - Class II: None
      - Class III: None
  - Not applicable: -

**IATA**
- UN number: UN1018
- UN proper shipping name: Carbon monoxide, compressed
- UN hazard class(es): 2.3 (2) (1)
- Packing group: -
- Specific precautions: -
- Additional information: 
  - United States Inventory:
    - Code: CSNI
    - Chemical or physical hazard:
      - Class I: None
      - Class II: None
      - Class III: None
  - Not applicable: -

**Packaging**
- Packaging type: -
- Special precautions: -
- Additional information: 
  - United States Inventory:
    - Code: CSNI
    - Chemical or physical hazard:
      - Class I: None
      - Class II: None
      - Class III: None
  - Not applicable: -

**Environmental**
- No.
- Na.
- Na.
- Na.
- Additional information: 
  - United States Inventory:
    - Code: CSNI
    - Chemical or physical hazard:
      - Class I: None
      - Class II: None
      - Class III: None
  - Not applicable: -

**United States Inventory**
- Code: CSNI
- Chemical or physical hazard:
  - Class I: None
  - Class II: None
  - Class III: None
- Not applicable: -

**Transport in bulk according to Annex II of MARPOL**
- Not available.

**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.

### Section 15. Regulatory information

**U.S. Federal regulations**
- Source: TSCA (1976/1980)
- Exception: Partial
- Not determined
- United States inventory (TSCA Title III): This material is listed or exempted.

**Clean Air Act Section 112**
- Source: TSCA (1976/1980)
- Exception: Partial
- Not determined
- United States inventory (TSCA Title III): This material is listed or exempted.

**Clean Air Act Section 602**
- Source: TSCA (1976/1980)
- Exception: Partial
- Not determined
- United States inventory (TSCA Title III): This material is listed or exempted.
### Section 16. Other information

<table>
<thead>
<tr>
<th>History</th>
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<td>5/12/2015</td>
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<td>5/12/2015</td>
<td></td>
</tr>
<tr>
<td>Version</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Key to abbreviations</td>
<td>ATE = Acute Toxicity Estimate</td>
<td></td>
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<tr>
<td></td>
<td>BCF = Bioconcentration Factor</td>
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<tr>
<td></td>
<td>IATA = International Air Transport Association</td>
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<tr>
<td></td>
<td>IED = International Edible Oils Directory</td>
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<tr>
<td></td>
<td>IMDG = International Maritime Dangerous Goods</td>
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<tr>
<td></td>
<td>LogPow = Logarithm of the octanol-water partition coefficient</td>
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<td></td>
<td>MARPOL = International Convention for the Prevention of Pollution From Ships</td>
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<tr>
<td></td>
<td>UN = United Nations</td>
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<tr>
<td></td>
<td>AHAM = American Hygiene Association</td>
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<tr>
<td>CAS = Chemical Abstracts Service</td>
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<tr>
<td>CEPA = Canadian Environmental Protection Act</td>
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</tr>
<tr>
<td>CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act</td>
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<tr>
<td>CER = Comprehensive Environmental Response</td>
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<td></td>
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<tr>
<td>CPR = Controlled Products Regulations</td>
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<tr>
<td>DIL = Domestic Substances List</td>
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<td></td>
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<tr>
<td>GHS = Global Harmonization System</td>
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<tr>
<td>IARC = International Agency for Research on Cancer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICAC = International Civil Aviation Organization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LF = Lethal dose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LD = Lethal dose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NSDS = Non-Domestic Substances List</td>
<td></td>
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</tr>
<tr>
<td>NSC = National Institute for Occupational Safety and Health</td>
<td></td>
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</tr>
<tr>
<td>TDG = Canadian Transportation of Dangerous Goods Act and Regulations</td>
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</tr>
<tr>
<td>TLV = Threshold Limit Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSCA = Toxic Substances Control Act</td>
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<tr>
<td>WESL = Workplace Environmental Exposure Level</td>
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<tr>
<td>WHMIS = Canadian Workplace Hazardous Material Information System</td>
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</tbody>
</table>

### Section 15. Regulatory information

| Chemical Weapons | Not listed |   |
| Convention List Schedule I |   |   |
| Chemical Weapons Convention List Schedule II | Not listed |   |
| Chemical Weapons Convention List Schedule III | Not listed |   |

### Section 16. Other information

| Canada WHMIS (Canada) |   |   |
| Class A: Compressed gas |   |   |
| Class B-1: Flammable gas |   |   |
| Class D-1A: Material causing immediate and serious toxic effects (Very toxic) |   |   |
| Class D-2A: Material causing other toxic effects (Very toxic) |   |   |
| Class E: Toxic substances |   |   |
| Class F: Inert |   |   |
| Canada ARP | This material is listed |   |
| Canadian HPR: This material is 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 |   |   |

### Reference

References: Not available.

* Indicates information that has changed from previously issued version.

### 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.

---

**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 minimum hazards or risks, and 4 representing significant hazards or risks. Although HMIS ratings are not required on SDSs under 29 CFR 1910.1200, the prepare may choose to provide them. HMIS ratings are to be used with a fully implemented HMIS program. HMIS is a registered mark of the National Paint & Coatings Association (NPCA). HMIS materials may be purchased exclusively from J. D. Keller (800) 327-8866.

The customer is responsible for determining the PPE code for this material.
EYE CONTACT: None
SKIN CONTACT: None
CHRONIC EFFECTS: None
OTHER EFFECTS OF OVEREXPOSURE: None

EXPOSURE INFORMATION:
ROUTE OF ENTRY: Inhalation
TARGET ORGAN: None
EFFECT: Asphyxiation (suffocation)
SYMPTOMS: Exposure to an oxygen-deficient atmosphere (<19.5%) may cause dizziness, loss of consciousness, nausea, vomiting, excess salivation, diminished mental alertness, loss of consciousness, and death.

MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None
CARCINOGENIC POTENTIAL: Hydrogen is not listed by IARC, NTP, or OSHA.

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: AUTOIGNITION: Flammable gas
FLAMMABLE LIMITS: 565.5 C (1000 F) LOWER: 4% UPPER: 74%

EXTINGUISHING MEDIA: CO2, dry chemical, water spray or fog for surrounding area. 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 container with water spray from maximum distance, taking care not to expose unflamed flames. If flames are accidentally extinguished, explosive reignition may occur. Stop flow of gas if a gas leak is stopped using water spray. Continuing cooling water spray.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Benzene with a pale blue, very visible flame. Hydrogen is easily ignited with low-intensity 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 should 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. If leaking 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 match stick to make the flame visible.

SECTION 7. HANDLING AND STORAGE

Safe Handling: Use a non-sparking tool. Avoid breathing vapor or gas. Avoid contact with skin and eyes.

STORAGE: Store under cover in a cool, dry place.

SECTION 8. EXPOSURE CONTROLS

VENTILATION: Local exhaust ventilation should be provided to control and dilute airborne concentrations.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE: Gas
MELTING POINT: -252.9°C (-424.2°F)
BOILING POINT: -240.4°C (-392.9°F)
VAPOR PRESSURE: 1 atm at 25°C (77°F)
VAPOR DENSITY (Air = 1): 0.088
VAPOR DENSITY (Water = 1): 0.088
DENSITY: 0.089 g/L (20°C / 68°F)

SECTION 10. STABILITY AND REACTIVITY

STABILITY: Stable under normal conditions.
REACTIVITY: Hydrogen reacts with many substances to form products of combustion.

SECTION 11. TOXICological INFORMATION

TOXICITY: Asphyxiant.

SECTION 12. ECOLOGICAL INFORMATION

ECOTOXICITY: None known.

SECTION 13. DISPOSAL CONSIDERATIONS

DISPOSAL: Disposal should be in accordance with local, state, and federal regulations.

SECTION 14. TRANSPORTATION INFORMATION

TRANSPORTATION SYMBOLS: UN2895, UN2833, UN1073, UN1061

SECTION 15. REGULATORY INFORMATION

REGULATIONS: None

SECTION 16. OTHER INFORMATION

HARMFUL EFFECTS: Asphyxiant.

CONCLUSION: Hydrogen is an asphyxiant. It should be noted that other suffocation could occur. The lower flammability limit of hydrogen in air would be exceeded possible, causing an oxygen-deficient and explosive atmosphere. Exposure to concentrations may cause dizziness, headaches, nausea, and unconsciousness. Exposure to atmospheres containing 0-10% 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 gas.

SECTION 12. ECOLOGICAL INFORMATION

No adverse ecological effects are expected. Hydrogen does not contain any Class I or Class II ozone depleting chemicals (40 CFR Part 82). Hydrogen is not listed as a marine pollutant by DOT (40 CFR Part 171).

SECTION 13. DISPOSAL

WASTE DISPOSAL METHOD: Do not attempt to dispose of residual or unused 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 ELIMINATED POINT. THIS WILL BE IN AN ISOLATED AREA AWAY FROM SPILL SOURCES.

SECTION 14. TRANSPORTATION

DOT/MARPAL Shipping Name: Hydrogen, compressed
HAZARD CLASS: 2.1 (Flammable Gas)
IDENTIFICATION NUMBER: UN-048
PRODUCT RG: None

SHIPPING LABELS: Flammable gas.
PLACARD (When required): Flammable gas.

SPECIAL SHIPPIING INFORMATION: Cylinder should be transported in a secure upright position in a well-ventilated truck. Never transport in passenger compartment of a vehicle. Shipment of compressed gas cylinders which have not been filled with the owner's consent is a violation of Federal law (49 CFR Parts 172, 301 (a)).

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS

EPA - ENVIRONMENTAL PROTECTION AGENCY
CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1980
(40 CFR Parts 117 and 302)
Reportable Quantity (RQ): None

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 left unattended. Hydrogen cylinders should not be stored in a temperature exceeding 125°F (52°C). Cylinders of hydrogen should be separated from oxygen cylinders or other cylinders by a minimum distance of 20 ft. or by a barrier of non-conductive material at least 8 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 drop, roll, slide or drop. Use a suitable hand truck for cylinder movement. Post "No Smoking or Open Flame" 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 valves before connecting it, since self-ignition may occur. Hydrogen is a light gas 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 you experience difficulty operating cylinder valve, discontinue use and contact supplier. Use only approved CGA 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 over-tight or rusted caps. 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 designed 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 6. 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%.

RESPIRATORY PROTECTION:
General Use: None
Emergency Use: All supplied respirators are required 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 glasses are recommended when handling cylinders.

SECTION 8. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE AND STATE: Colorless gas at normal temperature and pressure.
ODOR: Odorless

MOLECULAR WEIGHT: 2.016

BOLING POINT (at m.p.) -423.0°F (-258.8°C)

SPECIFIC GRAVITY ( AIR=1) 0.0690

FREEZING POINT (MELTING POINT) -343.4°F (-209.2°C)

VAPOR PRESSURE (at 76°F) Not applicable

GAS DENSITY (at 60°F, 21.1°C and 1 atm) 0.0662 lb/ft³ (0.0842 kg/m³)

SOLUBILITY IN WATER (at 60°F, 21.1°C and 1 atm) 0.0192 lb/lb (11.093 kg/kg)

SPECIFIC VOLUME (at 70°F, 21.1°C and 1 atm) 192 lb/ft³ (11.093 kg/m³)
THE DOW CHEMICAL COMPANY
MATERIAL SAFETY DATA SHEET

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Dow Chemical Canada Inc. encourages and expects you to read and understand the entire MSDS, as there is important information throughout the document. Dow expects you to follow the precautions identified in this document unless your use conditions would necessitate other appropriate methods or actions.

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

1.1 IDENTIFICATION

Product Name: MONOETHANOLAMINE

1.2 COMPANY IDENTIFICATION

The Dow Chemical Company
Midland, MI 48640

1.3 EMERGENCY TELEPHONE NUMBER

24-HOUR EMERGENCY TELEPHONE NUMBER: (888)636-4400.
Customer Information Number: 1-800-256-2406.

SARA: Superfund Amendments and Reauthorization Act

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 Part 355).

Extremely Hazardous Substances: None

Threshold Planning Quantity (TPQ): None

SECTION 311/312: Requires submission of material safety data sheets (MSDS) 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 315: 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.

40 CFR PART 68: Risk Management for Chemical Accidental Releases. Requires the development
and implementation of risk management programs for facilities that manufacture, use, store, or
otherwise handle regulated substances in quantities that exceed specified thresholds.

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 (4,536 kg) or greater, is
covered under this regulation.

TSCA: Toxic Substance-Control Act. Hydrogen is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

facilities to develop a process safety management program based on Threshold Quantities (TQ) of
highly hazardous chemicals.

Hydrogen is not listed in Appendix A as a highly hazardous chemical. However, any process
that involves a flammable gas on site in one location, in quantities of 10,000 pounds (4,536 kg)
or greater, is covered under this regulation unless it is used as fuel.

SECTION 16. OTHER INFORMATION

OTHER INFORMATION:

NFPA RATINGS:

- HEALTH: = 0
- FLAMMABILITY: = 4
- REACTIVITY: = 0
- SPECIAL: = SA (OSHA recommends this to designate simple asphyxiant)

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Product Name: MONOETHANOLAMINE
MSDS#: 1502

Eye Contact: Liquid causes severe irritation, experienced as discomfort or pain, excess blinking 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 possible 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 Overexposure

Effects of Repeated Overexposure: Repeated overexposure may cause damage to kidneys 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.

2. COMPOSITION INFORMATION

Component | CAS # | Amount (% WW)
---|---|---
Monethanolamine | 141-43-6 | >= 99.5 %

3. HAZARDS IDENTIFICATION

3.1 EMERGENCY OVERVIEW

Appearance: Colorless

Physical State: Liquid

Odor: Ammoniacal

Hazards of product: USE STAY AWAY FROM EYES OR SKIN. HARMFUL IF INHALED OR ABSORBED THROUGH SKIN.

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.
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 clean-up 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 on 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: Monothalamine and iron form a complex molecule, triethanolamine-iron. This material can spontaneously decompose at temperatures between 130° and 180°C, and has
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Protective Gloves: Polyvinyl chloride coated rubber.
Other Protective Equipment: Eye bath, safety shower, and chemical apron.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical State: Liquid
Appearance: Colorless
Odor: Ammoniakal
Flash Point - Closed Cup: 96 °C 205 °F Pensky-Martens Closed Cup ASTM D 93
Flash Point - Open Cup: 104 °C 220 °F Cleveland Open Cup ASTM D 92
Flammable 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 °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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been suspected of causing a fire in a nearly empty storage tank containing a header of MEA in contact with carbon steel steam coils. If steam coil heating is used, low pressure steam in stainless steel coils is preferred. Since this same mechanism may occur in drums, take care when handling drums of MEA with heating coils and maintain temperature below 130°C.

8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

8.1 EXPOSURE LIMITS

Component Exposure Limits Skin Form
Monooethanolamine 3 ppm TWA ACGIH 6 ppm STEL ACGIH 3 ppm TWA OSHA 6 mg/m3 TWA OSHA

In the Exposure Limits Chart above, if there is no specific qualifier (i.e., Aerial) listed in the Form Column for a particular limit, the listed limit includes all airborne forms of the substance that can be inhaled.

A "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.
Material Safety Data Sheet

**Peroral**
Combined effects for males and females:

**Major Signs:** sluggishness, lacrimation, prostration, kyphosis, unsteady gait, emaciation, palor, red or brown discharge on perioral, perineal, and perineal fur.

**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 - 3.36) ml/kg; slope = 5.06; 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, audible breathing in one, abdominal distension, prostration in one, emaciation.

**Gross Pathology:** numerous organs discolored, hemorrhaged intestines, stomachs and intestines 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): 0.92

Percent Volatiles: 100 W%

10. **STABILITY AND REACTIVITY**

10.1 **STABILITY/INSTABILITY** Stable.

**Conditions to Avoid:** Temperatures above 250 degrees C. May undergo self-sustaining thermal decomposition. See Section 7.2 for additional information on storage stability.


10.2 **HAZARDOUS POLYMERIZATION** Will not occur.

11. **TOXICOLOGICAL INFORMATION**

The following information is applicable to monoethanolamine.

**ACUTE TOXICITY**

**Peroral**

**Rat, male; LD50 = 1.19** (0.79 - 1.80) ml/kg; slope = 3.84

**Time to Death:** 0 to 12 days.

**Peroral**

**Rat, female; LD50 = 1.07** (0.72 - 1.59) ml/kg; slope = 4.06

**Time to Death:** 0 to 12 days.
GENETIC TOXICOLOGY

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 ethanalamine-1,2-C14 in the intact rat, tissue slices, and homogenates results in 94% of the dose in the liver, spleen, kidneys, heart, testis, and diaphragm and 11.5% as CO2, 8 hr after intraperitoneal administration. The liver was the most active tissue followed by the heart and brain. MELA is incorporated into the liver phosphatidylethanolamines 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. A laboratory study suggests that rats given high doses of MEA by gavage produced increased embryotoxic death, growth retardation and some malformations (hydroxyproline/hydroxyproline). 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</th>
<th>0%</th>
<th>75%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>90%</td>
<td>75%</td>
<td>100%</td>
</tr>
</tbody>
</table>

BOD (% Oxygen consumption)

<table>
<thead>
<tr>
<th>Day</th>
<th>52%</th>
<th>73%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>52%</td>
<td>73%</td>
<td>90%</td>
</tr>
</tbody>
</table>

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Gross Pathology: nothing remarkable.

IRRITATION

Skin: Rabbit: 4-hour occluded contact: 0.5 ml
Results: severe erythema, edema and necrosis with subsequent ulceration and scabbing, severe iritis and conjunctival irritation with necrosis and hemorrhages, healed by 21 days.

Eye: Rabbit: 0.005 ml
Results: severe corneal injury with vascularization and corneal deformation, severe iritis, severe conjunctival irritation with necrosis, and hemorrhages, healed by 21 days.

REPEATED EXPOSURE

In a 4-week dietary study with rats, guinea pigs, and dogs reported in the literature, doses varied up to 521 ppm over durations ranging from 3.5-12 wk for rats, 3.5 wk for guinea pigs, and 4-13 wk for dogs. Major signs at high exposures included mortality, severe stress, bleeding, and behavior changes. Histopathological changes were observed in lungs and nasal mucosa in guinea pigs and in livers and kidneys in guinea pigs and dogs. All exposures involved showed skin histopathology.

In an inhalation study with rats at doses up to 160 ppm for up to 6 months presented in literature, major signs included decreased body weights, altered hematological parameters, altered urine chemistries, and altered histopathology. The study concluded that the liver and kidney are the target organs.

In 4-week dietary study with rats at doses up to 2670 mg/kg/day, major signs at 1250 mg/kg/day were deaths, kidney, and liver histopathology. Altered liver and kidney weights were observed at 940 mg/kg/day.

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 literature, doses 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 embryofetal toxicity and teratogenicity. No increases in malformation rate or growth retardation were observed in fetuses or pups, indicating that MELA was not embryotoxic or teratogenic in the rat following gavage exposure. In a ferret study with rats, doses up to 229 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 125 mg/kg/day for maternal toxicity, and greater than 225 mg/kg/day for embryofetal toxicity 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 embryofetal toxicity and teratogenicity.
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 by the substance is not 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 1-800-258-2478 or 1-868-880-1598 (U.S.); or 1-800-331-6401 (Canada) for further details.

14. TRANSPORT INFORMATION

14.1 U.S. D.O.T.

NON-BULK
Proper Shipping Name: ETHANOAMINE
Hazard Class: II
ID Number: UN1491
Packing Group: P I II

BULK
Proper Shipping Name: ETHANOAMINE
Hazard Class: II
ID Number: UN1491
Packing Group: P I I

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 Aquatic Invertebrates
Daphnia: 48 h, LC50
Result value: 32 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: 125 mg/L

12.3 FURTHER INFORMATION

THODCARB
Theoretical Oxygen Demand (THOD) - calculated: 1.31 mg/L

THODMAT
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
MATERIAL SAFETY DATA SHEET

15.2 STATE/LOCAL

Pennsylvania (Worker and Community Right to Know Act): Pennsylvania Hazardous Substances List and/or Pennsylvania Environmental Hazardous Substance List

The following product components are classed in the Pennsylvania Hazardous Substance List and/or the Pennsylvania Environmental Substance List, and are present at levels which require reporting.

Component: Monoethanolamine
CAS #: 141-43-5
Amount: < 0.100000%

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 SCAGMIR Rule 443.1 (South Coast Air Quality Management District Rule 443.1, Labeling of Materials Containing Organic Solvents)

VOC: Vapor pressure 0.2 mmHg @ 20°C
10.14 g/l VOC
10.16 g/l 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

MATERIAL SAFETY DATA SHEET

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.

Suregery Amendments and Reauthorization Act of 1996 Title II: 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.

Suregery Amendments and Reauthorization Act of 1996 Title III: Emergency Planning and Community Right to Know Act Sections 311 and 312

Delayed (Chronic) Health Hazard: No
Fire 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.

TSCA - Substances Control Act (TSCA)

All components of this product are on the TSCA inventory or are exempt from TSCA Inventory requirements.
MATERIAL SAFETY DATA SHEET

Product Name: MONOETHANOLAMINE
MDSH: 1522
Effective Date: 06/17/2003
Page 16 of 17

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 1-600-331-6451 (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 notated by the bold, double bars in left-hand margin throughout this document.

16.5 LEGEND

Bacteria/Algae  Non Acclimated Bacteria
F  Fire
H  Health
HG  Industrial Hygiene Guideline
NA  Not available
NFPA  National Fire Protection Association
O  Oxidizer
R  Reactivity
TS  Trade secret
TARGET ORGAN: None
MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: None
CARCINOGENICITY: Methane is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA (Substant 2).

SECTION 4. FIRST AID MEASURES

EYE CONTACT: No treatment necessary.
INHALATION: Not applicable
INGESTION: Do not attempt to feed air. If not breathing, administer artificial respiration. If breathing is difficult, administer oxygen. Obtain prompt medical attention.
SKIN CONTACT: No treatment necessary.
NOTE TO PHYSICIAN: Treatment of overexposure should be directed at the control of symptoms and the clinical condition.

SECTION 5. FIRE FIGHTING MEASURES

FLASH POINT: -50°F (-56°C)
FLAMMABLE RANGE: 5.0% - 15%
EXTINGUISHING MEDIA: Dry chemical, carbon dioxide, or water.

SPECIAL FIRE FIGHTING INSTRUCTIONS: Evaluate all 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 re-ignition of a flammable gas mixture. Keep adjacent cylinders cool by spraying with large amounts of water until the fire burns itself 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, and provide adequate ventilation. Use a flammable gas meter (screw-on type) calibrated for methane to monitor concentration. Never enter an area where Methane concentration is greater than 1.5% (which is 20% of the lower flammable limit). Use a proper protective equipment (SCBA and fire resistant suit). Shut off source of gas if possible. Isolate any cylinder. If leak is from 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. Storage areas must meet National Electrical Codes for class I hazardous areas. Flammable storage areas must be separated from oxygen and other oxidizers by a minimum distance of 10 ft. or by a barrier of non-combustible materials at least 5 ft. high having a fire resistance rating of at least 1 hour. Full or half-stored or new cylinders need to be stored in the storage area. Do not allow storage temperature to exceed 120°F (50°C). Avoid storing in damp or wet areas. Do not store close to flammable liquids or gases. Do not store gas cylinders near paints or other flammable materials. Full and empty cylinders should be segregated. Use a flammable gas detectable system to prevent gas 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.

MANUFACTURER: Air Products and Chemicals, Inc.
7251 Hamilton Boulevard
Allentown, PA 18195 - 1101

PRODUCT INFORMATION: (800) 752-1597

SECTION 2. COMPOSITION / INFORMATION ON INGREDIENTS

Methane is packaged as pure product (>99%).
CAS NUMBER: 74-82-5
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 5.0%. High concentrations that can cause rapid suffocation are within the flammable range and should not be entered.

EMERGENCY TELEPHONE NUMBERS
800-523-0374 in Continental U.S., Canada and Puerto Rico
610-481-7711 outside U.S.

ACUTE POTENTIAL HEALTH EFFECTS
REPRESENTATIVE ROUTES OF EXPOSURE:

EYE CONTACT: No harmful effect.
INHALATION: Not applicable
INGESTION: 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 15.5%) 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. Methane, in contact with an oxygen deficient and an explosive atmosphere.

SKIN CONTACT: No harmful effect.

POTENTIAL HEALTH EFFECTS OF REPEATED EXPOSURE:
ROUTE OF ENTRY: None
SYMPTOMS: None
SECTION 12. ECOCLOGICAL INFORMATION

AQUATIC TOXICITY: Not determined
MOBILITY: Not determined
PERMEABILITY AND BIOACCUMULABILITY: Not determined
POTENTIAL TO BIOACCUMULATE: Not determined

REMARKS: This product does not contain any Class I or Class II ozone depleting chemicals.

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 (e.g., 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 characteristics (i.e., ignitability, corrosivity, toxicity, reactivity). Waste streams must be characterized by the user to meet federal, state, and local requirements.

SECTION 14. TRANSPORT INFORMATION

GOT SHIPPING NAME: Methane, compressed
HAZARD CLASS: 2.1
IDENTIFICATION NUMBER: UN1917
SHIPPING LABELS: Flammable gas
PLACARD (When required): Flammable 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. Ensure cylinder valve is properly closed. Valve outlet cap has been reinstalled. Valve protection cap is secured before shipping cylinder.

CAUTION: Compressed gas cylinders shall not be refilled except by qualified producers of compressed gases. Removal 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 (NAAERG #): 115

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS

EPA - ENVIRONMENTAL PROTECTION AGENCY

Releasable Quantity (RG): None

SARA TITLE III: Emergency Planning and Notification (40 CFR Part 355)
Emergency Hazardous Substances: Methane is not listed.
Threshold Planning Quantity (TPQ): None
Releasable Quantity (RG): None

SECTIONS 303/313: Hazardous Chemical Reporting (40 CFR Part 370)
IMMEDIATE HEALTH: Yes
PRESSURE: Yes
DELAYED HEALTH: No
REACTION: No
PIE: Yes

SECTION 311: Toxic Chemical Release Reporting (40 CFR Part 372)
Methane does not require reporting under Section 311.

SECTION 16. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS:
VENTILATION: Provide adequate natural or explosion-proof ventilation to prevent accumulation of gas concentrations above 1.5% Methane (20% of LEL).

RESPIRATORY PROTECTION:
Emergency Use: Do not enter areas where Methane concentration is greater than 1.0% (20% of the LEL). Exposure to concentrations below 1.2% do not require respiratory protection.

EYE PROTECTION: Safety glasses and/or face shield.

SKIN PROTECTION: Leather gloves for handling cylinders. Fire resistant suit and gloves in emergency response.

OTHER PROTECTIVE EQUIPMENT: Safety shoes are recommended when handling cylinders.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE, Odor and State: Colorless, odorless, flammable gas.
MOLAR WEIGHT: 16.04
BOILING POINT (1 atm): -252.7 °F (-161.5 °C)
SPECIFIC GRAVITY (Air = 1): 0.554
FREEZE POINT/MELT POINT: -246.5 °F (-162.5 °C)
VAPOR PRESSURE (M/104 g at 21°C): Permanent, noncondensable gas.
GAS DENSITY (lb/ft³ @ 60°F) and (°F): 0.042 lb/ft³
SOLUBILITY IN WATER (g/100 g): 3.3 ml gas / 150 ml

SECTION 10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Stable.
CONDITIONS TO AVOID: Cyinders should not be exposed to temperatures in excess of 125 °F (52 °C).
INCOMPATIBILITY (Materials to Avoid): Oxygen, Halogens and Oxidizers.

REACTION:
A) HAZARDOUS DECOMPOSITION PRODUCTS: None
B) HAZARDOUS POLYMERIZATION: None

SECTION 11. TOXICOLOGICAL INFORMATION

LC50 (Inhalation): Not applicable. Slight asphyxiant.
LD50 (Oral): Not applicable
LD50 (Dermal): Not applicable

SKIN CORROSION: Methane is not corrosive to the skin.

ADDITIONAL NOTES: None

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MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION

PRODUCT NAME: Nitrogen, compressed
CHEMICAL NAME: Nitrogen
FORMULA: N₂
SYNONYM(S): Nitrogen gas, Oxidizing Nitrogen, GN
MANUFACTURER: Air Products and Chemicals, Inc.
7221 Hamilton Boulevard
Allentown, PA 18105 - 1001

PRODUCT INFORMATION:
MSDS NUMBER: 1071
REVISION: 5
REVIEW DATE: March 1994

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS

Nitrogen is sold as pure product > 99%
CAS NUMBER: 7727-37-9
EXPOSURE LIMITS:
OSHA: Not established
ACGIH: 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 asphyxiation when concentrations are sufficient to reduce oxygen levels below 19.5%. Self Contained Breathing Apparatus (SCBA) may be required.

EMERGENCY TELEPHONE NUMBERS:
080-523-0374 Continental U.S., Canada and Puerto Rico
610-691-7111 other locations

POTENTIAL HEALTH EFFECTS INFORMATION:
INHALATION: Simple asphyxiant. Nitrogen is non-toxic but may cause asphyxiation by diluting the oxygen in air. Lack of sufficient oxygen can cause serious injury or death.
SKIN CONTACT: No adverse effect.
EYE CONTACT: No adverse effect.

EXPOSURE INFORMATION:
ROUTE OF ENTRY: Inhalation
TARGET ORGANS: None

SECTION 4. first AID PROCEDURES

FIRST AID:
Inhalation: If exposed, move to fresh air. Call a physician immediately. Provide artificial respiration if needed. Do not give by mouth.
Skin Contact: Wash with soap and water. If irritation develops, seek medical attention immediately.
Eye Contact: Flush immediately with plenty of water for 15 minutes. Seek medical attention immediately.

SECTION 5. FIRE FIGHTING PROCEDURES

FLAMMABILITY: N/A
EXTINGUISHING MEDIA: Water, foam, dry chemical, CO₂
SPREAD: N/A
SPECIAL FIRE FIGHTING PROCEDURE: Not applicable

SECTION 6. ACCIDENTAL RELEASE MEASURES

CLEAN UP:
Inhalation: If exposed, move to fresh air. Call a physician immediately. Provide artificial respiration if needed. Do not give by mouth.
Skin Contact: Wash with soap and water. If irritation develops, seek medical attention immediately.
Eye Contact: Flush immediately with plenty of water for 15 minutes. Seek medical attention immediately.

SECTION 7. HANDLING AND STORAGE

UNCOMPROMISE STORAGE:
Incompatible Materials: None

SECTION 8. EXPOSURE LIMITS

OSHA:
ACGIH:
NIOSH:

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE: Gas
MELTING POINT: -210°C
BOILING POINT: -195.7°C
DENSITY: 0.806 g/cm³
VAPOR PRESSURE: N/A

SECTION 10. STABILITY AND REACTIVITY

REACTION HAZARDS:
STABILITY: Stable
SPECIAL HAZARDS:

SECTION 11. TOXICOLOGICAL INFORMATION

HARMFUL CONCENTRATIONS:
INHALATION:
Skin Contact:
Eye Contact:

SECTION 12. ECOLOGICAL INFORMATION

SECTION 13. DISPOSAL CONSIDERATIONS

SECTION 14. TRANSPORT INFORMATION

TRANSPORT PRODUCT CODE:
UN NO.: N/A
CLASS: N/A
RISK PHRASES:
SPECIAL REQUIREMENTS:

SECTION 15. OTHER INFORMATION

NFPA RATING:
HEALTH: 1
FLAMMABILITY: 0
REACTIVITY: 0
SPECIAL: NA

HMS RATING:
HEALTH: 0
FLAMMABILITY: 0
REACTIVITY: 0
SPECIAL: N/A

*NA denotes "Not Applicable" per Compressed Gas Association recommendation.
damage valve causing a leak to occur. Use a special cap wrench or adjustable spanner wrench to remove over tight 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. (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 29 CFR 1910.146 (confined space entry), is essential.

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### SECTION 8. PERSONAL PROTECTION / EXPOSURE CONTROL

**ENGINEERING CONTROLS:** Provide good ventilation and/or 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 and escape pack in areas where oxygen concentration is less than 19.5%. An purifying respirator will not provide protection.

**OTHER PROTECTIVE EQUIPMENT:** Safety glasses. Safety shoes and leather work gloves are recommended when handling cylinders.

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### SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

**APPEARANCE:** Colorless gas

**ODOR:** Odorless

**MOLECULAR WEIGHT:** 28.01

**BOILING POINT:** Liquid, -210.0 °F (-149.0 °C)

**SPECIFIC GRAVITY:** (Air = 1.000) 0.967

**SPECIFIC VOLUME:** (at 70 °F and 1 atm) 1.08 ft³/lb (0.087 m³/kg)

**FREEZING POINT/MELTING POINT:** -475.8 °F (-277.0 °C)

**VAPOR PRESSURE:** Not applicable at 70 °F

**GAS DENSITY:** (at 70 °F and 1 atm) 0.077 lb/ft³ (1.153 kg/m³)

**SOLUBILITY IN WATER** (mol/L at 35°F [2°C]): 0.003

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### SECTION 10. STABILITY AND REACTIVITY

**CHEMICAL STABILITY:** Stable

**CONDITIONS TO AVOID:** None

**INCOMPATIBILITY:** None

**HAZARDOUS DECOMPOSITION PRODUCTS:** None

**HAZARDOUS POLYMERIZATION:** Will not occur.

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### SECTION 11. TOXICOLOGICAL INFORMATION

Nitrogen is a simple asphyxiant.

**EFFECT:** Asphyxiation (suffocation)

**SYMPTOMS:** Exposure to an oxygen deficient atmosphere (<19.5%) may cause dizziness, drowsiness, nausea, vomiting, unconsciousness, diminished mental alertness, loss of consciousness and death. Exposure to atmospheres containing 0-10% or less oxygen will bring about unconsciousness without warning and so quickly that the individuals cannot help themselves.

**MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE:** None

**CARCINOGENIC POTENTIAL:** Nitrogen is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA.

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### SECTION 4. FIRST AID

**INHALATION:** Persons suffering from lack of oxygen 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:** Not applicable.

**SKIN CONTACT:** Not applicable.

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### SECTION 5. FIRE AND EXPLOSION

**FLASH POINT:** Autoclonization

**FLAMMABILITY LIMITS:** Not applicable

**NONFLAMMABLE**

**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 may rupture if pressure relief devices fail to function.

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### SECTION 6. 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 container valve, call the Air Products emergency telephone number. If leak is in user’s system close cylinder valve and vent pressure before attempting repairs.

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### SECTION 7. 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 slide 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 overfill cylinder to increase pressure or discharge rate. 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
40 CFR Part 68 - Risk Management 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.

TSCA - TOXIC SUBSTANCES CONTROL ACT: Nitrogen is listed on the TSCA inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

29 CFR 1910.119 - Process Safety Management of Highly Hazardous Chemicals: Requires facilities to develop a process safety management program based on Threshold Quantities (TQ) of highly hazardous chemicals.

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 16. OTHER INFORMATION

<table>
<thead>
<tr>
<th>NFPA RATINGS</th>
<th>HMR RATINGS</th>
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<tbody>
<tr>
<td>HEALTH: 0</td>
<td>HEALTH: 0</td>
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<tr>
<td>FLAMMABILITY: 0</td>
<td>FLAMMABILITY: 0</td>
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<tr>
<td>REACTIVITY: 0</td>
<td>REACTIVITY: 0</td>
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<tr>
<td>SPECIAL: SA*</td>
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*Compressed Gas Association recommendation to designate simple asphyxiant.

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SECTION 10. 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 depletion chemicals. Nitrogen is not listed as a marine pollutant by DOT (49 CFR 171).

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 SHIPING LABEL: Nonflammable Gas
IDENTIFICATION NUMBER: UN1006
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 retailed 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 requires notification to the National Response Center of a release of quantities of hazardous substances equal to or greater than their 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 (TQ) and release reporting based on reportable quantities (RQ) of EPA's extremely hazardous substances (40 CFR 355).

Nitrogen is not listed as an extremely hazardous substance.

Threshold Planning Quantity (TQ): None

SECTION 311/312: Require submission of material safety data sheets (MSDS) and chemical inventory reporting with identification of EPA defined hazardous classes. The hazard classes for this product are:

IMMEDIATE HEALTH: No
DELAYED HEALTH: No
PRESSURE: Yes
REACTIVITY: No
FIRE: No

SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR 372.

Nitrogen does not require reporting under Section 313.
EXPOSURE INFORMATION:
ROUTE OF ENTRY: Inhalation
TARGET ORGANS: Eyes, central nervous system
MEDICAL CONDITIONS AGGRAVATED BY OVEREXPOSURE: Patients with chronic obstructive pulmonary disease retain carbon dioxide abnormally. If oxygen is administered to them, raising the oxygen concentration in the blood suppresses their breathing and raises their retained carbon dioxide to a dangerous level.
CARCINOGENIC POTENTIAL: Oxygen is not listed as a carcinogen or potential carcinogen by NTP, IARC, or OSHA Subpart Z.

SECTION 4. FIRST AID
INHALATION: Move victim to fresh air or if in 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 phenothiazines, clonidine, and chlorpromazine, increases the susceptibility to toxicity from oxygen at high pressures. Animal studies also indicate that vitamin E deficiency may increase susceptibility to oxygen toxicity.
Alveolar obstruction during high oxygen tension may cause alveolar collapse following absorption of the oxygen. Similarity, occlusion of the bronchial 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 and who exhibit overt oxygen toxicity should have ophthalmologic examinations.

SECTION 5. FIRE AND EXPLOSION
FLASH POINT: Not applicable
AUTODISTRIBUTION: Nonflammable
FLAMMABLE LIMITS: Nonflammable
EXTINGUISHING MEDIA: Oxygen is nonflammable 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 supporting the fire. Interim attempt cool containers with water spray from minimum 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 incombustible in air may burn in the presence of an oxygen enriched atmosphere (greater than 23%). The most oxidizing material may burn and offer no protection in oxygen. Oxygen reacts vigorously with some solvents, such as light hydrocarbons, which may react explosively with water or oil, grease, and other hydrocarbon materials. Pressure in a container can build up due to heat and it may rupture if pressure relief devices should 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 should fail to function.

MATERIAL SAFETY DATA SHEET

SECTION 1. PRODUCT IDENTIFICATION
PRODUCT NAME: Oxygen, Compressed
CHEMICAL NAME: Oxygen
FORMULA: O₂
SYNONYMS: Oxygen gas, Elemental Oxygen, GOX
MANUFACTURER: Air Products and Chemicals, Inc.
2201 Hamilton Boulevard
Allentown, PA 18105 - 1501
PRODUCT INFORMATION: 1-800-752-1597
MSSD NUMBER: 1012
REVISION: 3
REVISION DATE: January 1985
REVIEW DATE: August 1997

SECTION 2. COMPOSITION/INFORMATION ON INGREDIENTS
Oxygen is listed as a product > 99.5% by volume.
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 odorless, colorless, nonflammable gas stored in cylinders at high pressure. It is an oxidizing gas and vigorously accelerates combustion. Keep away from oils or grease. Exposure to the human body 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) 523-6374 Continental U.S., Canada and Puerto Rico
(918) 487-7771 other locations

POTENTIAL HEALTH EFFECTS INFORMATION:
INHALATION: Breathing 90% 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, altered sensation, visual and hearing disturbances, muscular twitches, unconsciousness, and convulsions. Breathing oxygen under pressure may cause precipitation of adaptation to darkness and reduced peripheral vision.
EYE/SKIN CONTACT: No adverse effect.
SECTION 6. ACCIDENTAL RELEASE MEASURES

Evaluate all personnel from affected area. Shut off source of oxygen if possible. Increase ventilation in release area. Personnel who have been exposed to high concentrations of oxygen should seek fresh air immediately. If oxygen is confined or open area for 30 minutes before going into a confined space or near an ignition source, 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 storage areas where salt or other corrosive materials are present. Cylinders should be separated from flammables by a minimum distance of 20 ft or by a barrier of non-combustible material at least 6 ft high. Cylinder valves should be covered to prevent entry of foreign materials and the 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 slide cylinders. 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 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 G-4-1. Carbon steel, stainless steel, copper, brass, nickel and their alloys are materials of construction that can be used in oxygen service. Use gauging 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 read and understand the manufacturer’s instructions and the precautionary label on the products. Never strike an arc on a compressed gas cylinder or make a cylinder a part of an electrical circuit.

SPECIAL REQUIREMENTS: Always store and handle compressed gases in accordance with Compressed Gas Association, Inc. (ph: 703-412-0626) 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 watered or washed by spud or dried by water or air. Compressed gas cylinders shall not be stored near other flammable or explosive materials. Compressed gas cylinders shall be stored in a temperature controlled environment in an area separate from other flammable or explosive materials.

SECTION 8. PERSONAL PROTECTION / EXPOSURE CONTROL

ENGINEERING CONTROLS: Provide ventilation and/or local exhaust to prevent accumulation of high concentrations of gas (greater than 23%).

RESPIRATORY PROTECTION: GENERAL USE: None required

EMERGENCY: Use SCBA to do possibility of fire when concentrations exceed 23%.

OTHER PROTECTIVE EQUIPMENT: Safety shoes and work gloves are recommended when handling cylinders. Clothing exposed to high concentrations may retain oxygen 30 minutes or longer and become a potential fire hazard. Stay away from ignition sources.
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. An oxygen label may be used for domestic shipment in the United States and Canada in place of the Nonflammable and Oxidizer labels (49 CFR Part 172).

SECTION 15. REGULATORY INFORMATION

U.S. FEDERAL REGULATIONS:

EPA - ENVIRONMENTAL PROTECTION AGENCY:

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act of 1986 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).

SECTION 303: Requires submission of material safety data sheets (MSDSs) and chemical inventory reporting with identification at EPA-defined hazardous classes. The hazard classes for this product are:

- WAREHOUSE: No
- PESTICIDE: Yes
- DELAYED: No
- REACTIVITY: No
- FIRE: Yes

SECTION 313: Requires submission of annual reports of releases of toxic chemicals that appear in 49 CFR 372.

- Oxygen is not listed as a toxic chemical.

40 CFR PART 60: Risk Management 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.

Oxygen is not listed as a regulated substance.

TOXIC SUBSTANCE CONTROL ACT (TSCA): Oxygen is listed on the TSCA Inventory.

OSHA - OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:


Oxygen is not listed as a Highly Hazardous Chemical.

STATE REGULATIONS:

CALIFORNIA:

Proposition 65: This product does NOT contain any listed substances for which the State of California requires warning under this statute.

SCAQMD Rule: VOC = Not applicable

SECTION 9. 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 /24.4 °C and 1 atm): 12.08 ft³/ft³ (0.754 m³/m³)

FREEZING / MELTING POINT: -381.6 °F (-235.9 °C)

VAPOR PRESSURE: Not applicable at 70°F

GAS DENSITY (at 70°F /24.4 °C and 1 atm): 0.083 lb/ft³ (1.326 kg/m³)

SOLUBILITY IN WATER (Vol./Vol.): 0.549

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. TOXICOLOGICAL INFORMATION

At 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 central nervous system (CNS) toxicity occurs. Symptoms include nausea, vomiting, dizziness or vertigo, musle 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 12. ECOLOGICAL INFORMATION

The atmosphere contains 21% oxygen. No adverse ecological effects are expected. Oxygen does not contain any Class I or Class II ozone-depleting chemicals. Oxygen is not listed as a marine pollutant by DOT (49 CFR 171).

SECTION 13. DISPOSAL

UNUSED PRODUCT / EMPTY CONTAINER: Return container and unused product to supplier. Do not attempt to dispose of residual or unused quantities.

DISPOSAL: For emergency disposal, secure cylinder and slowly discharge gas to the atmosphere in a well-ventilated area or outdoors.

SECTION 14. TRANSPORTATION

DOT HAZARD CLASS: 2.2 (Nonflammable Gas)

DOT SHIPPING NAME: Oxygen, compressed

IDENTIFICATION NUMBER: UN 1072

REPORTABLE QUANTITY (RQ): None

PLACARD: Nonflammable Gas or Oxygen
Ferrelgas Material Safety Data Sheet - Propane

Ferrelgas
One Liberty Plaza
Liberty, MO 64058

Section 1: Emergency Information

24 Hour Emergency Number
Call 1-800-349-0590 (Collect) in case of emergencies involving propane.

Warning!
- Extremely flammable compressed gas.
- Asphyxiant at high concentrations.
- Make contact with liquid carbon tetrachloride and isopropyl alcohol.
- Dilute vapor or smoke using a water spray雾雾

NIPRIS Hazard rating
Health hazard = 4
Fire hazard = 4
Reactivity = 0

Where:
0 = Low
1 = High
2 = Moderate
3 = High

General MDRS assistance
Call R-5-700-100 and ask to speak with the Safety Department for general assistance with questions about this MDRS.

Section 2: Hazardous Components/Identity Information

Product
Propane (liquid)

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>85 - 100</td>
</tr>
<tr>
<td>Propane</td>
<td>15751-1</td>
<td>0 - 15</td>
</tr>
<tr>
<td>Isobutane</td>
<td>10687-96-4</td>
<td>0 - 2.5</td>
</tr>
<tr>
<td>Isobutane</td>
<td>10682-0</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Ethane</td>
<td>74-86-1</td>
<td>0 - 0.5</td>
</tr>
<tr>
<td>Ethane</td>
<td>74-83-3</td>
<td>0.1005</td>
</tr>
</tbody>
</table>

Material Data Safety Sheet Page 1
Section 4: Emergency and First Aid Procedures

**Prepare**: Follow these procedures in case of personal injuries resulting from use of this product.

**Eye contact with liquid**: Flush eyes with water. Get medical attention.

**Skin contact with liquid**: Flush with water. If possible, wash off. 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>Colorless gas, hazard under pressure</td>
</tr>
<tr>
<td>Boiling point</td>
<td>-4 degrees F</td>
</tr>
<tr>
<td>Evaporation of water (mixture)</td>
<td>24 degrees F</td>
</tr>
<tr>
<td>Flash point</td>
<td>-156 degrees F</td>
</tr>
<tr>
<td>Laminar vapor pressure ratio</td>
<td>1.270</td>
</tr>
<tr>
<td>Molecular weight</td>
<td>46.056</td>
</tr>
<tr>
<td>Solubility in water</td>
<td>High</td>
</tr>
<tr>
<td>Specific gravity (liquid)</td>
<td>0.904, 0.913 (Water = 1)</td>
</tr>
<tr>
<td>Specific gravity (vapors)</td>
<td>1.95, 1.96</td>
</tr>
<tr>
<td>Vapor pressure (maximum)</td>
<td>208 mm Hg (2914 degrees F)</td>
</tr>
</tbody>
</table>

Section 6: Fire and Explosion Hazards

**Flammability limits**: Flammability limits by volume at air.
- Lower 2.15 percent
- Upper 8.4 percent

**Ignition temperatures**: Auto-ignition temperature is 940 degrees F.

**Extinguishing media**: Allow product to burn if source cannot be shut off safely.
- Class B/C or A/B/C dry chemical or halon extinguishers are 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 (flamethrow).

**Inhalation**: This product is classified as a simple agent.
- High vapor concentrations may produce reversible central nervous system depression (tachycardia).
- Higher concentrations may produce apnea.

**Ingestion**: Ingestion is unlikely.

**Signs and symptoms**: Eye or skin burns (flamethrow) as noted previously.
- Eye irritation, central nervous system depression may be evidenced by paresthesia, headache, dizziness, and anorexia in contact cases.
- Exposure to high concentrations may cause loss of consciousness. Death may occur.
- Application may be evidenced by muscle weakness, tremors, hyperventilation, loss of consciousness, death.

**Aggravated medical conditions**: Caution is recommended for personnel with pre-existing central nervous system or chronic respiratory disorders.

**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 the table to determine the allowable exposure limits for personnel.

<table>
<thead>
<tr>
<th>ORSHA</th>
<th>PEL/TWA</th>
<th>TLV/TWA</th>
<th>ACGIH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preexposure</td>
<td>300 ppm</td>
<td>200 ppm</td>
<td>Not established</td>
</tr>
<tr>
<td>Preexposure</td>
<td>300 ppm</td>
<td>200 ppm</td>
<td>Not established</td>
</tr>
</tbody>
</table>

**Cardiac effects**: While there is no evidence that exposure to substantially acceptable levels of hydrocarbons have produced cardiac effects in humans, animal studies have shown that inhalation of high vapor levels of the components of this product have produced cardiac sensitization. Such sensitization may cause cardiac changes in heart rhythm. This latter effect was shown to be enhanced by exposure of the identical animal-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 adrenal cortex.
Section 9: Precautions For Safe Handling and Use

Training
- Train all personnel involved in handling propylene in proper handling and operating procedures.
- Document all training.

Handling and storing
- Handle and store propylene in compliance with OSHA and local fire codes.
- Keep containers away from heat sources and temperatures exceeding 110 degrees F.
- Do not store near any container.
- Store and transport containers with relief valves in vapor space.
- Keep all containers sealed when not in use.
- Keep protective caps (if applicable) on containers when not in use.

DOT cylinders
- Take precautions when using DOT cylinders.
  - Periodically inspect and replace DOT cylinders in accordance with DOT and NFPA codes and Compressed Gas Association recommendations.
  - Store and use cylinders with valves off and the relief valves in the container vapor space.
  - Stan all valves and follow recomended procedures before exchanging cylinder.

Special precautions
- Containers, even those that have been emptied, can contain explosive vapors.
  - Do not cut, weld, grind, or produce sparks/special operations on or near containers.

Precautionary statements

- Warning: Any中文 of release, even a small one, may result in a dangerous situation.
- Effluent manure is the preferred means of exposure for propylene. Although effluent manure has excellent deflagrating properties, it is recognized that any release will be completely effective as a warning agent in every circumstance (NFPA 25, 1995 edition).
- Ingestion of which could cause loss of their effectiveness in every instance, but are not limited to:
  - Other may cause due to chemical evolution in improperly assayed water and atmospheres.
  - Other may be absorbed and absorbed by the walls of containers and distribution systems.
  - Other is the gas escaping from unregulated containers may be absorbed by certain species of such gases.
  - Effluents of the effluent may be reduced by cold temperatures.
  - Other, such as from cooking or from a nearby source may react with or cover up the effluent from other areas.
  - Exposure to the effluents of propylene for extended periods of time may affect a person's ability to detect the odor.
  - Personal disabilities or the use of alcohol, tobacco, or drugs may decrease a person's ability to detect the odor.

Section 10: Transportation Requirements

DOT shipping name
- Liquid Petroleum Gas

DOT classification
- Division 2.1 (Flammable Gas)

Other transportation requirements
- UN 9075
- Material Safety Data Sheet: North American Industrial Classification System (NAICS) Number 45492

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Section 6: Fire and Explosion Hazards

Special fire fighting procedures and precautions
- Extremely flammable. Containers may explode if not sufficiently cooled with water spray.
- Extinguish surrounding area of any released personnel and isolates. Do not enter confined fire area without full body gear (helmet with face shield, brass work gloves, and rubber boots) and a positive-pressure NIOSH approved self-contained breathing apparatus.

Section 7: Reactivity

Stability and compatibility polymers
- This product is stable; it may be handled normally.
- Avoid contact with strong oxidizing agents. Avoid buildup of static electricity.
- Prevent vapor concretion.

Hazardous decomposition products
- Confirm that all exposed hazardous organic products may be handled during combustion.

Section 8: Employee Protection

Respiratory protection
- Use a NIOSH approved respirator as required when airborne exposure limits are exceeded.
- An approved NIOSH approved respirator or an air purifying respirator for respiratory hazards.

Protective clothing
- Avoid liquid contact with eyes or skin.
- Wear protective glasses or goggles as appropriate.
- Wear protective clothing as appropriate.

Section 9: Precautions For Safe Handling and Use

Release, spill or leak procedures
- Warning: Extremely flammable.
  - Eliminate sources of ignition.
  - Indicate isolated areas and apply water to unnecessary or non-essential personnel.
  - Keep smoke and flame out of low areas.
  - Notify local authorities.
  - Dispose of used containers with water spray.
  - Use only if safe to do so.
## 1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

**MATHESON TRIGAS, INC.**

**150 Allen Road Suite 302**

Basking Ridge, New Jersey 07920

Information: 1-508-416-2505

Emergency Contact: CHEMICAL 1-800-424-5300

Calls Originating Outside the US: 703-527-3887 (Collect Calls Accepted)

**SUBSTANCE:** PROPYLENE

**TRADE NAMES/SYNONYMS:** MTG MDL# 77; PROPENE; METHYLTHIENE; METHYLETHYLINE; 1-PROPYLENE; 1-PROPENE; UN 1077; CI116; MATN3830; RTECS UJ040000

**CHEMICAL FAMILY:** hydrocarbons, aliphatic

**CREATION DATE:** Jan 24 1988

**REVISION DATE:** Dec 11 2008

## 2. COMPOSITION, INFORMATION ON INGREDIENTS

**COMPONENT:** PROPYLENE

**CAS NUMBER:** 115-07-1

**PERCENTAGE:** 100.0

## 3. HAZARDS IDENTIFICATION

**NFPA RATING (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

**POSSIBLE HEALTH EFFECTS:**

**INHALATION:**

**SHORT TERM EXPOSURE:** tearing, nausea, vomiting, symptoms of drunkenness, 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 172 (BAPA Section 113) as:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXX</td>
<td></td>
</tr>
</tbody>
</table>

**OSHA PELs:** This product does not contain any hazardous air contaminants as defined by 51 FR 61252.

**BCRA Information:** This product is not subject to 60 CFR 308.18 as the disposal of hazardous waste.

**More Regulatory Information:** This product is not subject to the Resource Conservation and Recovery Act, 42 U.S.C. 6901 et seq., or the Solid Waste Disposal Act, 42 U.S.C. 6901 et seq., or the Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. 9601 et seq., or the Clean Air Act, 42 U.S.C. 7401 et seq., or the Clean Water Act, 33 U.S.C. 1251 et seq., or the Toxic Substances Control Act, 15 U.S.C. 2601 et seq., or any other Federal or State legislation that places additional requirements on this product.

**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 and its packaging.

## Section 12: Supplemental Information

**Disclaimer of Liability:** The information in this MSDS was obtained from sources which we believe are reliable. However, the information is provided without any warranty, express or implied, regarding its correctness.

This product when handled, stored, used, or disposal of this product in accordance with good industrial practice.

**Issue Information:** This MSDS replaces all previous editions:

- Issued July, 2008
- Issued by: Scott Fernseher, Manager of Safety

**Material Safety Data Sheet**
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 station 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 nitrile 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

4. FIRST AID MEASURES

INHALATION: If adverse effects 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: If feasible or freezing occurs, 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 wash affected parts in cold water. Get immediate medical attention.

EYE CONTACT: Clean with 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. Vapor/mist are explosive above flash point. The vapor is heavier than air. Exposure of glass may ignite at distant ignition source and flash back. Electrostatic discharges may be generated by flow or agitation resulting in ignition or explosion.

EXTINGUISHING MEDIA: Carbon dioxide, regular dry chemical

Large fires: Flood with fire resistant spray.

FIRE FIGHTING: Move container from fire area if it can be done without risk. Cool containers with water spray until well after the fire is out. Keep away from drums of flammable liquids. For fires in cargo or storage area. Cool containers with water from unburned hose holder ornearest nozzle until well after fire is out. If this is impossible, keep away all unnecessary people, isolate hazard area and deny entry. Let the fire burn. Withdraw immediately in case of rising sound from venting safety device or any indications of toxic gases 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: IARC: Human Inadequate Evidence, Animal Inadequate Evidence, Group 3; ACGIH: A4 - Not Classifiable as a Human Carcinogen
TARGET ORGANS: central nervous system
TUMORIGENIC DATA: Available
ADDITIONAL DATA: Mice/nineaths such as epinephrine may induce ventricular fibrillation

12. ECOLOGICAL INFORMATION

FATE AND TRANSPORT:
KOW: 223.87 (log Kow = 3.35) (estimated from water solubility)
KOC: 533.33 (log KOC = 2.73) (estimated from water solubility)
HENRY'S LAW CONSTANT: 9.6 x 10^-6 atm-m3/mol
BIOCONCENTRATION: 0.49 (estimated from water solubility)
AQUATIC PROCESSES: 1.6882019 hours (River Model: 1 m deep, 1 m/s flow, 3 m/s wind)
ENVIRONMENTAL SUMMARY: Relatively non-persistent in the environment. Leaches through the soil or the sediment at a slow rate. Accumulates very little in the bodies of living organisms. Moderately volatile from water.

13. DISPOSAL CONSIDERATIONS

Dispose in accordance with all applicable regulations. Subject to disposal regulations: U.S. EPA 40 CFR 262. Hazardous Waste Number(s): D001.

14. TRANSPORT INFORMATION

U.S. DOT 49 CFR 172.101:
PROPER SHIPING NAME: Propylene
ID NUMBER: UN1077
HAZARD CLASS OR DIVISION: 2.1
LABELING REQUIREMENTS: 2.1

For Unknown Concentrations or Immediately Dangerous to Life or Health -
Any equipment or apparatus that is operated in a pressure-demand or other positive-pressure mode in combination with an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive-pressure mode.
Any self-contained breathing apparatus that has a self-contained breathing apparatus, or is operated in a pressure-demand or other positive-pressure mode.

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE: gas
COLOR: colorless
ODOOR: Not available
MOLECULAR FORMULA: C3H6
BOILING POINT: -42.9°C
FREEZING POINT: -101°C
VAPOR PRESSURE: 0.6262 mmHg at 21°C
VAPOR DENSITY (air=1.0): 1.5
SPECIFIC GRAVITY: Not applicable
DENSITY: 1.785 g/L
WATER SOLUBILITY: 45%
PH: Not applicable
VOLATILITY: Not applicable
ODOOR THRESHOLD: Not available
EVAPORATION RATE: Not applicable
VISCOSITY: 0.1045 cp @ -90°C
COEFFICIENT OF WATER SOLUBILITY: Not applicable
SOLVENT SOLUBILITY: Soluble in alcohol, ether, acetone.
SIGMA-ALDRICH

SAFETY DATA SHEET

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifier(s)

Product name: Zirconium(V) oxide-yttria stabilized

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: 3000 Spruce Street

City: Philadelphia, PA 19104 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

Signal word: Warning

Hazard statement(s):

H315 Causes skin irritation.

H319 Causes serious eye irritation.

H335 May cause respiratory irritation.

Precautionary statement(s):

P261 Avoid breathing dust/fume/gas/mist/vapours/spray.

P264 Wash skin thoroughly after handling.

P271 Use only outdoors or in a well-ventilated area.

P280 Wear protective gloves/eye protection/face protection.

P302 + P352 IF ON SKIN: Wash with plenty of soap and water.

P304 + P340 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 any contact lenses if easy to do so.
5.2 Special hazards arising from the substance or mixture
Zirconium oxides, 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 area. 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 Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yttrium oxide</td>
<td>1344-36-0</td>
<td>TWA 1.000000 mg/m³</td>
<td>USA, ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA 1 mg/m³</td>
<td>USA, ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA 1 1 mg/l</td>
<td>USA, ACGIH 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
Bystander 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 Specific treatment (see supplementary first aid instructions on this label).

P321 References: see section 2.3.

P337 + P313 If skin irritation occurs: Get medical advice attention.

P332 Take off contaminated clothing and wash before reuse.

P403 + P233 Store in a well-ventilated place. Keep container tightly closed.

P405 Store locked up.

P901 Dispose of contents/container to an approved waste disposal plant.

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

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances
Synonyms
Yttrium oxide

Formula
Dy(Y2)2

Molecular weight
146.03 g/mol

CAS-No.
11448-68-6

3.2 Hazardous components

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconium (IV) oxide</td>
<td>Eye irritation</td>
<td>Skin Irr: 2; Eye Irr: 2X; B1ST O3 SE 3; H315, H316, H317</td>
</tr>
<tr>
<td>Yttrium oxide</td>
<td>Skin Irr: 2; B1ST O3 SE 3; H315, H317</td>
<td>~5% - &lt;10%</td>
</tr>
</tbody>
</table>

No components need to be disclosed according to the applicable regulations.

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
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

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

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

4.3 Indication of any immediate medical attention and special treatment needed

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

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

Source: I 373/46
10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

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

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects
Acute toxicity
No data available
Inhalation: No data available
Dermal: No data available
No data available
Skin corrosion/irritation: No data available
No data available
Sensory or organite irritation: No data available
No data available
Respiratory or skin sensitisation: No data available
No data available
Genotoxicity
No data available
Carcinogenicity
IARC: No component of this product is listed in IARC monographs.
NOP: No component of this product is listed in the National Cancer Institute's list.
OSHA: No component of this product is listed in OSHA's list.

Reproductive toxicity
No data available
No data available
Specific target organ toxicity - single exposure
No data available

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

- Appearance: Form: powder
- Odour: No data available
- Odour threshold: No data available
- pH: No data available
- Melting point/freezing point: Melting point: > 250 °C (482 °F)
- Initial boiling point and boiling range: No data available
- Flash point: Not applicable
- Evaporation rate: No data available
- Flammability (solid, gas): No data available
- Upper/lower flammable limits: No data available
- Explosive limits: No data available
- Vapour pressure: No data available
- Vapour density: No data available
- Relative density: No data available
- Water solubility: No data available
- Partition coefficient n-octanol/water: No data available
- Auto-ignition temperature: No data available
- Decomposition temperature: No data available
- Viscosity: No data available
- Explosive properties: No data available
- Oxidising properties: No data available

9.2 Other safety information
No data available
SARA 311/312 Hazards
Acute Health Hazard
Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components
Zirconium (IV) oxide, yttria stabilized
CAS-No: 114168-16-0
Revision Date: 13143-69

Yttrium oxide
CAS-No: 114168-16-0
Revision Date: 13143-69

New Jersey Right To Know Components
Zirconium (IV) oxide, yttria stabilized
CAS-No: 114168-16-0
Revision Date: 13143-69

Yttrium oxide
CAS-No: 114168-16-0
Revision Date: 13143-69

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.

15. OTHER INFORMATION

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

eye irrit. eye irritation
H315 Causes skin irritation.
H335 May cause respiratory irritation.
Skin Irr Skin irritation
STOT SE Specific target organ toxicity - single exposure

HMEG Rating
Health hazard: 2
Chronic Health Hazard: 0
Physical Hazard: 0

NIEHS Rating
Health hazard: 2
SKH Hazard: 0
Readability 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 SMEY – Americas Region
1-800-521-4858
Version: 4.12 Revision Date: 06/05/2015 Print Date: 04/05/2016

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.

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

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

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available
12.2 Persistence and degradability
No data available
12.3 Bioaccumulative potential
No data available
12.4 Mobility in soil
No data available
12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted
12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company. 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 Minimiss) reporting levels established by SARA Title III, Section 313.
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers
   Product name: Zinc nitrate hexahydrate
   Product Number: 06482
   Brand: Sigma-Aldrich
   CAS-No.: 10196-19-8

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: 3001 Spruce Street, Philadelphia, PA 19104 USA
   Telephone: +1 800-325-5832
   Fax: +1 800-325-5830

1.4 Emergency telephone number
   Emergency Phone #: (314) 776-6555

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture
   OHS Classification in accordance with 29 CFR 1910 (OSHA HCS).
   Skin irritation (Category 2), H315
   Eye irritation (Category 2A), H319

2.2 GHS Label elements, including precautionary statements
   Signal word: Danger
   Hazards statement(s):
   H315: Causes skin irritation.
   H319: Causes serious eye irritation.
   H335: May cause respiratory irritation.
   Precautionary statement(s):
   P210: Keep away from heat.
   P232: Keep away from clothing, combustible materials.
   Take any precaution to avoid mixing with combustibles.
   Avoid breathing dust/fume/gas/vapour/spray.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances
   | Formal name | CAS-No. |
   | N₂O₅·3H₂O | 10196-19-8 |

3.2 Hazardous components
   | Component | Classification | Concentration |
   | Zinc nitrate hexahydrate | On. Sit. 2, Acute Tox. 4, Sk. Irrit. 2, Eye Irrit. 3A, STOT SE 2, H272, H302, H315, H319, H335 | 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: Wash off with soap and plenty of water. Consult a physician.
   In case of eye contact: Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician. Continue rinsing eyes during transport to hospital.
   If swallowed: Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most Important symptoms and effects, both acute and delayed
   The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11.
4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media

Use water spray, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

Zinc oxide

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid 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

Sweep up and shovel. Contains spillage, and then collect with an electrically protected vacuum cleaner or by wet-breathing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal.

6.4 Reference to other sections

For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Further processing of solid materials may result in the formation of combustible dust. The potential for combustible dust formation should be taken into consideration before additional processing occurs. Provide appropriate exhaust ventilation at places where dust is formed. Keep away from sources of ignition. No smoking. Keep away from heat and sources of ignition.

For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

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

Hygroscopic.

Storage class (TRGS 510): Oxidising hazardous materials

7.3 Specific end uses

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

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters.

Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of working.
19. ECOLOGICAL INFORMATION

19.1 Toxicity
No data available

19.2 Persistence and degradability
No data available

19.3 Bioaccumulative potential
No data available

19.4 Mobility in soil
No data available

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

19.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and recycled solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dispose or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as unused product.
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 handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety—Americas Region
1-800-521-4956

Version: 3.5 Revision Date: 11/16/2014 Print Date: 04/01/2016

11. TRANSPORT INFORMATION

DOT (US)
UN number: 1544 Class: 5.1
Proper shipping name: Zinc nitrate
Reportable Quantity (RQ): 1000 lbs
Poison Inhalation Hazard: No

IMDG
UN number: 1544 Class: 5.1
Proper shipping name: Zinc nitrate

IATA
UN number: 1544 Class: 5.1
Proper shipping name: Zinc nitrate

15. REGULATORY INFORMATION

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

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

CAS-No. Revision Date
10156-15-6 1999-04-24

Massachusetts Right to Know Components
Zinc nitrate hexahydrate
CAS-No. Revision Date
10156-15-6 1999-04-24

Pennsylvania Right to Know Components
Zinc nitrate hexahydrate
CAS-No. Revision Date
10156-15-6 1999-04-24

New Jersey Right to Know Components
Zinc nitrate hexahydrate
CAS-No. Revision Date
10156-15-6 1999-04-24

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
H315 May cause respiratory irritation.
H319 Causes skin irritation.
H335 May cause respiratory irritation.
G2 Skin irritation