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Export of Marcellus Shale Gas

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Export of Marcellus Shale Gas

Abstract
The Marcellus Shale natural gas field that spans from West Virginia to New York is leading the recent surge in domestic energy production. Long an importer of natural gas, the United States will soon be able to export natural gas. Due to its low energy density however, natural gas must be converted to liquefied natural gas (LNG) before shipping to foreign markets. Liquefaction can occur at several different facilities: small-scale LNG plants, floating LNG operations, and retrofitted LNG import facilities. A design feasibility study is presented here to analyze the economics of retrofitting an existing LNG import facility into an LNG export plant.

The existing import facility is the Dominion Cove Point LNG plant located near Lusby, Maryland. This study sizes the export facility at 5 to 6 million tons per annum (MMTPA), which corresponds to a feed of about 750 million standard cubic feet per day of natural gas (MMscfd). In this process, natural gas is first precooled by propane and then liquefied with a mixed refrigerant blend of methane, ethane, propane, and nitrogen. One challenge is to minimize the large amount of mixed refrigerant used in this process. This can be done by optimizing the composition of the mixed refrigerant to reduce the amount needed to liquefy the natural gas.

After a comprehensive economic analysis, this proposed design is economically viable. This process has an estimated IRR of 23.5% and NPV of $219 million at a 20% discount rate, using an LNG selling price of $650 per ton. This 23.5% IRR is possible due to the retrofit advantages of some existing equipment and reduced construction time. Without these advantages, the IRR would be much less favorable at about 9.1%.

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Department of Chemical & Biomolecular Engineering

Senior Design Report

University of Pennsylvania

2014

Export of Marcellus Shale Gas

April 15th, 2014

Ryan Marschang
Steven Lee
Ann Hewitt
Tyler Moeller

University of Pennsylvania

Department of Chemical and Biomolecular Engineering

220 South 33rd Street

Philadelphia, PA 19104

Dear Dr. Holleran and Professor Fabiano,

Enclosed is our proposed process design for the liquefaction of natural gas produced from the Marcellus Shale and liquefied at the Cove Point import terminal facility. Our process is made up of three main parts: the propane pre-cooling section, the mixed refrigerant cooling section and most importantly the main cryogenic liquefaction section. This plant design will be extremely large, with a production capacity of 5.368 million tons per annum (MTPA) of liquefied natural gas. The following report details the process, equipment needs and costs, power requirements and economic analysis for the retrofit of the Cove Point facility.

Our proposed process design yields an NPV of $219 million with a very attractive IRR of 23.5%. The large NPV is commensurate with the large scale of this plant design.

Thank you for your assistance with this project.

Sincerely,

Ryan Marschang ______________________

Ann Hewitt ______________________

Ty Moeller ______________________

Steven Lee ______________________

Table of Contents

Section 1

Abstract

Abstract

The Marcellus Shale natural gas field that spans from West Virginia to New York is leading the recent surge in domestic energy production. Long an importer of natural gas, the United States will soon be able to export natural gas. Due to its low energy density however, natural gas must be converted to liquefied natural gas (LNG) before shipping to foreign markets. Liquefaction can occur at several different facilities: small-scale LNG plants, floating LNG operations, and retrofitted LNG import facilities. A design feasibility study is presented here to analyze the economics of retrofitting an existing LNG import facility into an LNG export plant.

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Section 2

Introduction and Background Information

2.1 Introduction and Background Information

The Marcellus Shale natural gas field that spans from West Virginia to New York is leading the recent surge in domestic energy production, with the United States government predicting that the U.S. will be a liquefied natural gas (LNG) exporter by 2016. [1] This development has prompted the need for more LNG export facilities in the United States. An inactive LNG import facility, Dominion Cove Point LNG in Maryland, has the necessary infrastructure to transport natural gas from the Marcellus Shale and could be retrofitted to export LNG to locations around the world.[2]

The Marcellus Shale field contains an estimated 177 trillion cubic feet of natural gas according to conservative estimates,[3] with the actual total likely much higher. Companies continue to look for efficient, cost-effective ways of transferring this fuel to profitable locations, extending across the country and beyond. The most feasible option for transporting natural gas farther than 1,500 km is as LNG, which is created through a series of processes involving removal of water and contaminants, liquefaction, refrigeration, and storage before eventual transportation.[4]

The project involves designing an LNG facility to convert Marcellus Shale natural gas for export to global markets. Existing pipeline infrastructure is in place for a facility on the East Coast. Using materials and knowledge gained from the chemical engineering curriculum, the team will design a liquefaction process consisting of multiple stages, including pre-feed

[1] U.S. Energy Information Administration. *Annual Energy Outlook 2012 Early Release Overview*., 2012. Web.
[2] Phillips, Susan. "**Marcellus Shale Exports Could Transform Global LNG Market**." 25 July 2013Web. <http://stateimpact.npr.org/pennsylvania/2013/07/25/marcellus-shale-exports-could-transform-global-lng-market/>.
[3] U.S. Energy Information Administration. "**Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays**." 8 July 2011Web. <http://www.eia.gov/analysis/studies/usshalegas/>.
[4] Choi, Michael. "**LNG for Petroleum Engineers**." *SPE Projects, Facilities & Construction* 6.04 (2011): 255. Web.

processing, liquefaction (refrigeration cycle), storage, product loading, and transportation. An efficient method of liquefaction to be considered is the Cascade process.[5]

A comparison of feasible LNG plant designs will be necessary. Floating LNG facilities are one alternative to traditional onshore plants. Another option is the retrofitting of the Dominion Cove Point LNG plant, which is currently set up as an import facility but could be converted to an export facility. This project envisions an extensive analysis of the conversion from import to export, which will be considered along with an appropriate process design of gas liquefaction.

In addition to a strong technical foundation and design, this project will also investigate the economics of the various plant possibilities. Determining the costs to produce, liquefy, and transport the LNG will elucidate whether the cost to retrofit the Cove Point facility is feasible from a financial standpoint, beyond its technical merits. The economic advantage of converting the Cove Point facility is that the LNG tankage, port, and other infrastructure is already in place, likely resulting in a lower capital investment compared to building a new LNG export facility from scratch.

Furthermore, this project will inspect the economics of exporting Marcellus Shale gas. With the recent closure of the vast majority of nuclear power plants in Japan, the nation is more reliant now than ever before on imported natural gas to satisfy its energy needs. In 2012, United States natural gas (NG) prices were at 2.76 $/mmbtu and Japan LNG prices were at 16.75 $/mmbtu in 2012, presenting a large U.S. economic opportunity for successful LNG production and export.[6] This project will present an economic analysis of a chemical process involving the

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5 Bowen, Ronald R., and Eric T. Cole. Cascade Refrigeration Process for Liquefaction of Natural Gas. . 25 Jan 2000.

6 BP. "Natural Gas Prices." 2013.Web. <http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy-2013/review-by-energy-type/natural-gas/natural-gas-prices.html>.

costs of constructing and operating an LNG facility and distribution to a market where LNG is in high demand. The LNG markets in other countries are often locked into long term contracts, unlike the natural gas market in the U.S., and this project will allow for the exploration of the current LNG financial landscape.

2.2 Project Charter

Project Name: Export of Marcellus Shale Gas

Project Leaders: Ann Hewitt
Steven Lee
Ryan Marschang
Tyler Moeller

Project Advisors: Professor Fabiano
Dr. Holleran

Specific Goals: To design a facility that provides the most economical transportation of natural gas from Marcellus Shale to abroad via liquefaction

Project Scope: *In-Scope:*

- Retrofit of Cove Point LNG export facility
- Building new facilities on Cove Point facility to expand capacity
- Analysis of different liquefaction design and construction processes
- Focus on liquefaction at LNG terminal

Out-of-Scope:

- Design of new LNG fleet technology
- Design of midstream facilities (i.e. pipelines to LNG plant)
- Design of re-gasification plant / technology
- Gas production from Marcellus

Deliverables:

- Design of 5.4 mtpa (approximate, assuming 94% onstream time)[7] capacity liquefaction facility, including:
  - Block diagram of scrubbing and liquefaction processes
  - Optimal plant locations and estimated footprint
  - Reaction kinetics and thermophysical property data
- Analysis of plant economics for different gas price scenarios
- Health, safety and environmental (HSE) analysis

Timeline:

- $3.4 to $3.8 billion project[8]
- 4-5 years (for construction)[9]
  - June 2012 - FERC (federal energy regulatory commission) pre-filing process
  - April 2013 - File FERC sections 3 and 7 applications
  - 1/2Q 2014 Receive FERC order issuing certificate and granting section 3 authority
  - 1/2Q 2014 Begin construction of the liquefaction facilities
  - In service by EOY 2017

[7] Bobby Strain Group. "LNG CONVERSION FACTORS." 2013.Web. <http://www.bobby-strain-group.com/BSG_LNG.htm>.
[8] Dominion Cove Point. "**The Case for Cove Point Export**." 2014.Web. <https://www.dom.com/business/gas-transmission/cove-point/>.
[9] Freeport LNG. "Freeport LNG's Liquefaction and Export Project." 2014.Web. <http://www.freeportlng.com/the_project.asp>.

2.3 Technology-Readiness Assessment (Innovation Map)

There are a larger number of natural gas liquefaction processes that have been developed and that are currently used in industry. Figure 2.1 helps break down classifications for these processes.

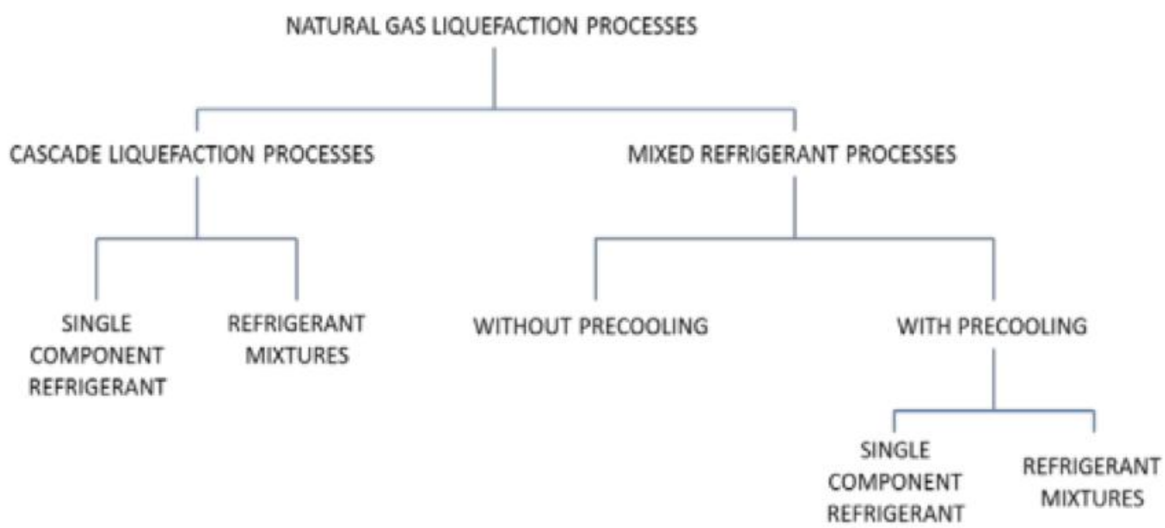


Figure 2.1: Classification of Natural Gas Liquefaction Processes

Single refrigeration cycles are useful as there fewer pieces of equipment to purchase. However, they can only handle small base loads. The fewer pieces of equipment translates into lower capital costs and usually higher operating efficiencies. Multiple refrigeration cycles are capable of handling larger base loads. Some of the common mixed refrigerant processes include the following: Linde process, Axens liquefin process, Technip-TEALARC, Technip-Snamprogetti, ExxonMobil Dual Multi-component and the Black and Veatch Prico Process. The more popular pure refrigerant cycles are the ConocoPhillips Simple Cascade and the CoP Enhanced Cascade cycles. The most popular refrigeration cycle is Air Product's APCI C3MR which is used in approximately 90% of all industrial processes.[10] The APCI C3MR is actually both a pure refrigerant process and a mixed refrigerant process. It involves a pre-cooling cycle with a pure refrigerant and then a subcooling cycle involving a main cryogenic heat exchanger utilizing a mixed refrigerant. While all of these potential processes were investigated the innovation map below looks at only the most popular ones for simplicity.

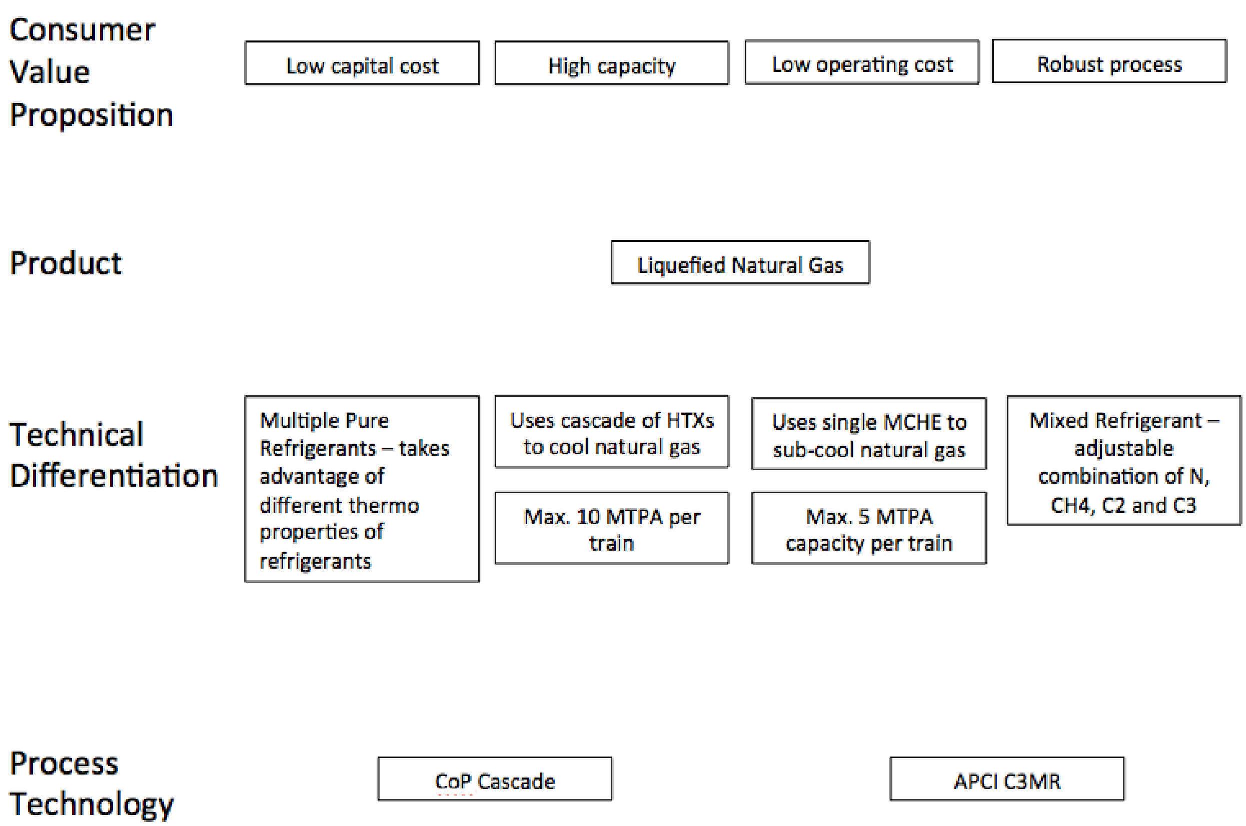


Figure 2.2: Innovation Map

[10] Intsok. "Shell Inc Presentation final I."Web. <http://www.intsok.com/style/downloads/Shell--Inc---Presentation-final-l.pdf>.

Section 3

Concept Stage

3.1 Market and Competitive Analysis

3.1.1 Natural Gas

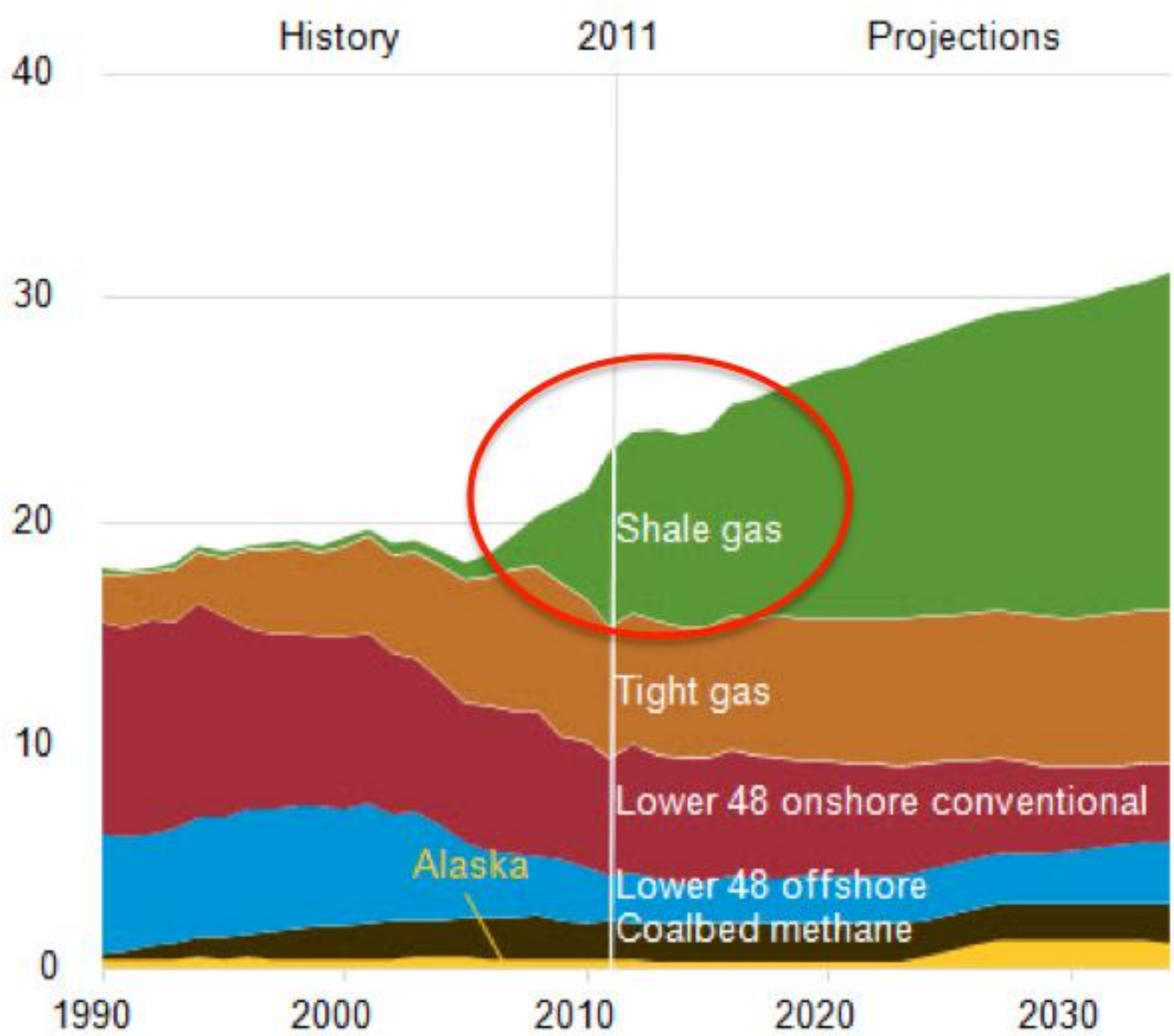


Figure 3.1: Natural gas production by source, 1999 - 2030 (trillion cubic feet)

Natural gas production has been rising tremendously because of the advent of fracturing technology that has unlocked massive shale gas reserves in the United States. It is estimated that there is approximately 2,500 trillion cubic feet of natural gas in the U.S. - which translates into a 100 year supply based on current and projected energy consumption. In the year 2000 shale gas was only 1% of American natural gas reserves and in 2013 it is 25% of natural gas reserves. This statistic demonstrates the extent of the growth in the industry. Natural gas is particularly useful as its combustion releases 29% less carbon dioxide than oil and 44% less than coil per btu of energy input. The reason for this is because of the high hydrogen to carbon ratio in the molecule. Given all of the concern with climate change and global warming in the past decade, any fuel that emits less carbon dioxide into the atmosphere is likely to experience greater demand moving forward into the future.

The counter side of this increased production is that natural gas prices have plummeted in the United States because of excess supply. As shown in the figure below, prices decreased from a peak of $13 per mmbtu to below $2 per mmbtu over the course of five years. One standard cubic foot of natural gas has a heat of combustion of around 1000 BTU, which is why the units of mmbtu are sometimes used instead of standard cubic feet.

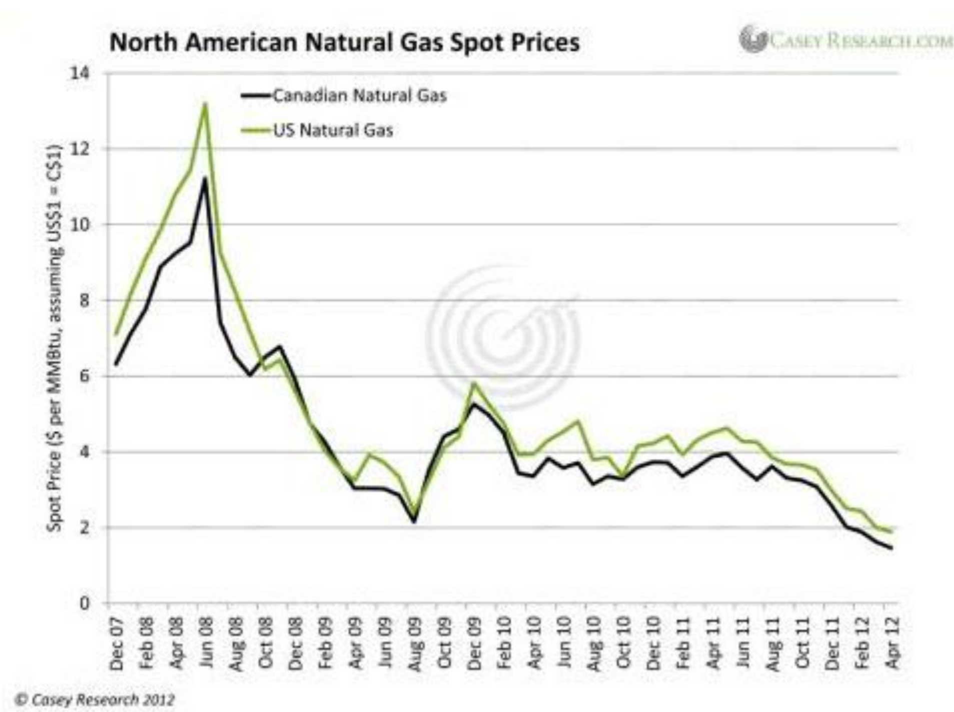


Figure 3.2: Natural gas spot prices, 2007 - 2012

The market for natural gas internationally is not very liquid. It is unlike oil which is a widely traded commodity where there are clear local and international benchmarks. Natural gas prices in markets around the world are very different - this being one of the drivers behind the proposal to liquefy natural gas and transport it to markets where the commodity is significantly more valuable. The figure below illustrates the difference in prices between five countries. The striking takeaway from the figure is that natural gas prices in Japan are near 18 cents per kWh whereas they are near 4 cents per kWh in the United States. The differential in price is far greater than the cost of transportation to and from both countries. Japan, South Korea and Taiwan are some of the biggest importers of LNG worldwide, representing 70% of all LNG consumption. This huge demand (and lack of supply) for natural gas is what drives up the prices in these markets.

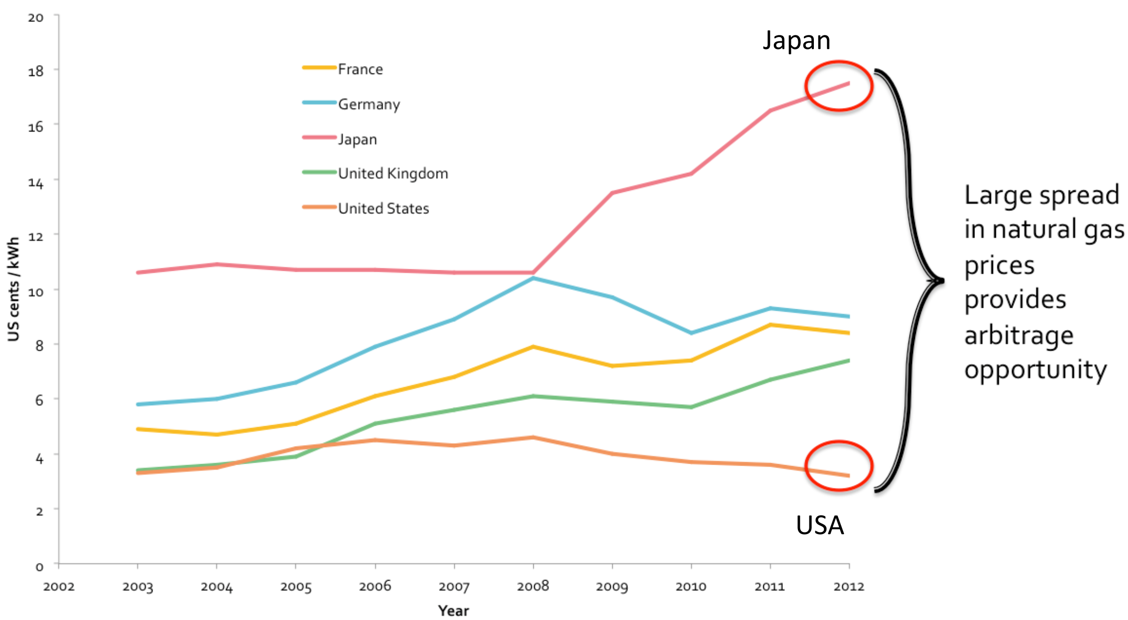


Figure 3.3: Price of natural gas in markets around the world

3.1.2 Liquefied Natural Gas

The LNG produced from this LNG export terminal at Cove Point will compete with all other sources of LNG around the globe. The world LNG supply capacity is currently at 300 MTPA and is growing rapidly. Furthermore, there are over 100 liquefaction trains already in operation around the world. However, there are only three LNG export facilities in the United States, none of which are on the East Coast and have access to the Marcellus Shale gas. The three LNG export terminals are: Cheniere's Sabine Pass in Cameron Parish, LA with a capacity of 2.2 Bcfd (billion cubic feet per day), Freeport LNG in Freeport, TX with a capacity of 1.4 Bcfd and Lake Charles Exports in Lake Charles, LA with a capacity of 2.0 Bcfd. The largest LNG export facility worldwide is the Rasgas facility in Qatar that has a capacity of 4.7 Bcfd.

Despite a larger supply of LNG, there is a quickly growing demand for LNG. World LNG demand is currently around 250 MTPA but it is expected to double by 2030.

3.2 Customer Requirements

The customer for this process is an entity such as government or corporation that is wishing to purchase liquefied natural gas. There are certain international standards that stipulate the composition at which liquefied natural gas can be officially bought and sold. Below is a list of typical LNG specifications. The LNG that is produced via the proposed plant design in this report must meet these standards in order to be sold at fair prices to international markets such as Japan. The specifications for LNG are more stringent that what is required for the non-liquefied gas that is transported via pipelines around the country. The purpose of natural gas specifications are to ensure corrosion prevention, avoid having liquid drop out of any pipelines and ensure heating performance if used as a fuel. LNG has additional requirements to prevent any freezing at cryogenic temperatures.

Table 3.1: LNG Specifications for International Markets

Component:	**Specification:** (mass %)
Methane	94.7% (minimum)
Ethane	4.8%
Propane	0.4%
Butane	0.06%
Pentane	0.01%
Hexane	0.01%
Helium	-
H2S	< 2 -4 ppmv < 0.25 grains/100scf
Total Sulfur Content	< 10 - 50 ppmv < 0.5 grains/100scf
CO2	< 50 ppmv
Hg	< 0.01 ug / Nm2 < 5 ng/m3
H2O	< 0.1 ppmv
Oxygen	< 0.01%
Nitrogen	< 1%
High Heating Value	985 - 1070 btu/scf
Heating Value	905 btu/scf 1047 btu/ft3
Wobbe Index	<1400 btu/cf

3.3 Preliminary Process Synthesis

We start our preliminary process synthesis by first analyzing the overall value chain for natural gas production and consumption as it relates to the LNG industry. The most general outline of this is shown in the figure below. Gas is produced from a natural gas reservoir and typically must be transported in the gaseous form via a pipeline. The gas is then liquefied by cooling it to -260F at an LNG export terminal. Cooling the gas shrinks it to 1/600th its original volume and increases the energy density to 20 MJ/L. The liquid gas is then shipped on tankers to a respective market overseas. The reason the gas is liquefied for transport is that after a certain distance it is more economical to transport gas via tankers in a liquefied state than it is to send in an extended reach pipeline. Once the gas reaches its destination it is re-gasified at an LNG import terminal and distributed for local consumption.

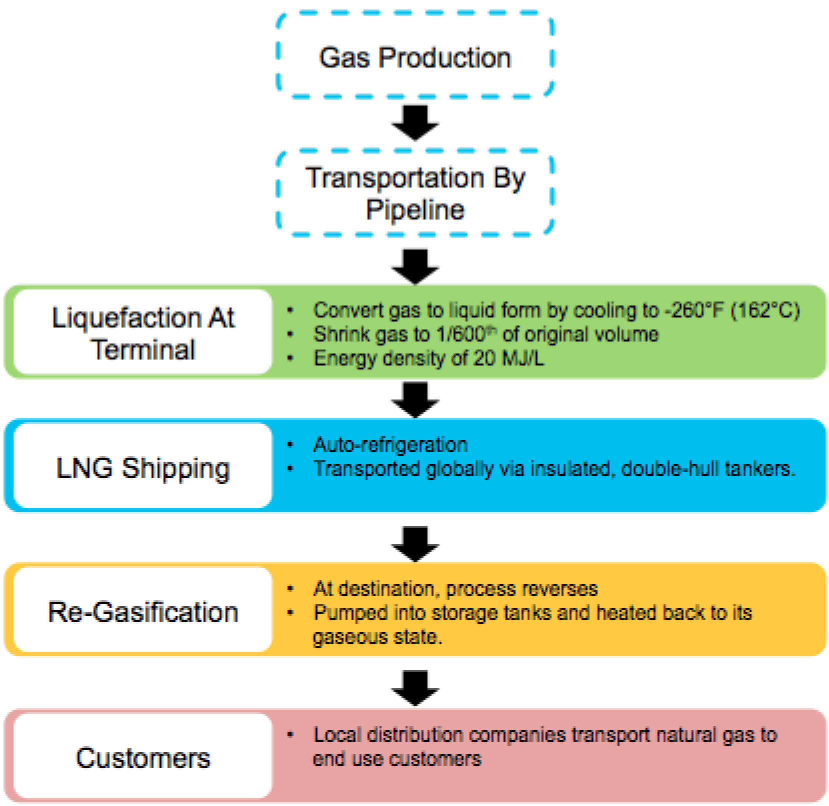


Figure 3.4: Value Chain - Production to Consumption of Natural Gas

3.4 Cove Point Facility Constraints Used to Estimate Capacity for LNG Export

In order to continue with the preliminary process synthesis we needed to set about outlining the constraints of the Cove Point facility. These constraints are crucial to estimating the capacity of the retrofitted plant. The current import facility features an offshore pier that can dock two 267,000 cubic meter ships at one time. The pier is over half a mile in length, is a mile offshore in approximately 43ft water depth. The facility has been approved to have 200 ships per year but in the past has around 85 to 90 ships per year. A single ship is capable of bringing 34M gallons of LNG. In terms of storage there is 14.6 BCF of above ground storage capacity. The LNG is pumped from ships at the offshore dock through a series of pipes to these insulated storage tanks. The existing plant has a 1.8 BCF send out capacity for taking in the LNG and re-gasifying it to be distributed in the United States. The plant connects to the major Mid-Atlantic gas transmission system consisting of the Transcontinental Gas Pipeline, Columbia Gas Transmission, and Dominion Transmission.

Based upon the capacity of the existing LNG import facility, a preliminary sizing of the LNG export retrofit was set at 5 to 6 million tons per annum (MMTPA), corresponding to an approximate feed of 750 million standard cubic feet per day of natural gas (MMscfd). Based on current production levels in the Marcellus Shale this feed rate will account for 1 to 5% of total natural gas production. This percentage will decline over time as total production increases in the region and there should be no issue procuring the feed supply. In the unlikely event that there is a supply shortage there is access to the nearby Utica Shale for additional natural gas. Information on the specific amount of natural gas flowing through the Mid-Atlantic gas transmission system is highly proprietary information, but the capacity is far in excess of 750 MMscfd. For reference, the Columbia Pipeline Group transports roughly 1.3 trillion cubic feet per year or 3.6 billion cubic feet per day. With this estimate for the feed and product, the preliminary design can be made more detailed.

Figure 3.5: Current Cove Point LNG Import Facility

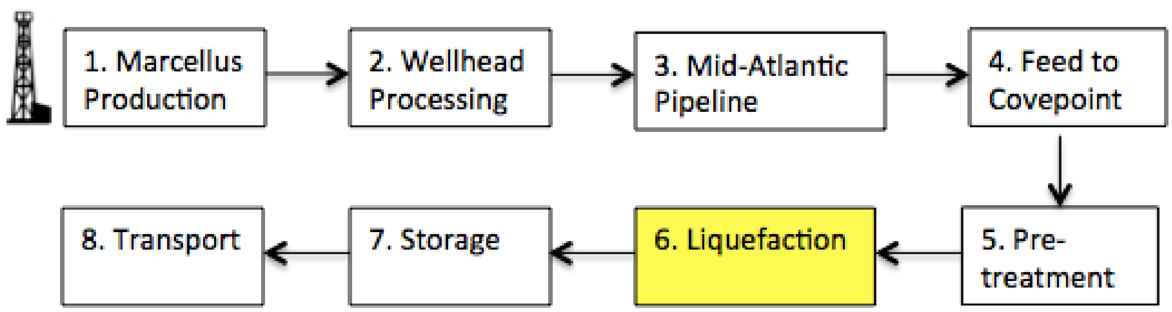


Figure 3.6: Proposed Preliminary Process Block Diagram

The proposed preliminary block diagram can be broken down into eight overall steps. In the first step the natural gas will be produced from the Marcellus Shale, with possible back up supply coming from the nearby Utica Shale. This gas is treated at the wellhead in Step 2 before entering into the Mid-Atlantic Pipeline in Step 3. The gas from these wells will be transported to the Cove Point plant via the Mid Atlantic Gas Transmission Pipeline System in Step 4. This pipeline has specifications for the composition of the fluid flowing through it and therefore the composition of the natural gas entering the facility is well defined. The natural gas will likely need to be pre-treated in Step 5 before beginning liquefaction in Step 6. Pre-treatment typically involves condensate removal, dehydration, CO2 removal, Hg removal, H2S removal and LPG fractionation. It is noted that some of these pre-treatment steps may be able to be incorporated into the liquefaction step. After the liquefaction step, the LNG is moved into storage before it is transported via LNG tankers to international markets. Step 6, the liquefaction process, is the core of this design project.

3.4.1 Marcellus Production

The Marcellus Shale, spanning across Pennsylvania, West Virginia, southeast Ohio and parts of New York, is the largest source of natural gas in the United States. Shale gas is natural gas that is trapped in very low permeable shale rock thus requiring the use of hydraulic fracturing to extract it. As the fracking technology has continued to improve the number of wells drilled in the United States is soaring. In 2012, 45,468 wells were drilled, the largest number of wells ever drilled in the United States. The heightened drilling is leading to large volumes of production. As of January 2013 the Marcellus Shale produced 7.81 BCF per day of natural gas. The Marcellus is 104,067 square miles with well spacing of 4.9 wells per square mile.

As for the most recent data from the EIA, the Marcellus was producing 14.3 BCF per day with over 100 active rigs being used to drill in the region. We can use this number to help gauge the sizing estimate of the Cove Point facility. It was estimated that 750 MMscfd would be fed to the plant for liquefaction and export. If this is the case it would represent roughly 5% of all Marcellus production as of today. With the expected growth in production from the Marcellus this percentage will certainly drop towards 1-2% within three to five year. Therefore there is certainly more than enough supply from the Marcellus to feed the Cove Point LNG export plant when built. Under any circumstances where there may be a shortfall of production to feed the plant there is always the nearby Utica Shale supply that could be accessed.

3.4.2 Wellhead Processing

Natural gas that is fed into any main gas pipeline transport system, in the United States, must meet certain specifications as will be listed in Step 3 below. Given these requirements, the natural gas that comes out of the ground at a particular well must be processed. The composition of raw natural gas that comes out of the ground is highly variable and depends on the type of reservoir, depth of well and location of well. This is often referred to in industry as 'wellhead processing'. Natural gas that does not meet these specifications can result in pipeline ruptures, operational troubles and pipeline deterioration. Wellhead processing involves removing contaminants such as hydrogen sulfide, carbon dioxide, nitrogen, water vapor and oxygen as well as removing natural gas liquids (NGLs) from the natural gas. In some instances the natural gas may need more extensive treatment before entering a pipeline and will be treated in an actual processing plant before being placed in high pressure, long distance pipeline.

Processing can include the following: gas-oil separators, condensate separators, dehydration, contaminant removal, nitrogen extraction, methane separation and fractionation.

3.4.3 Mid-Atlantic Pipeline

This system connects to Cove Point facility through an 88 mile pipeline. The Mid-Atlantic pipeline has certain constraints that dictate the composition of natural gas that will be fed to the Cove Point facility.

Table 3.2: Pipeline Composition Requirements

	(mol %)	Min.	Max.	
Main Components:				
	C1	75.0%	100.0%	
	C2	0.0%	10.0%	
	C3	0.0%	5.0%	
	C4 +	0.0%	2.5%	
	CO2	0.0%	4.0%	
	N2	0.0%	4.0%	
Trace Components:				
	Mercaptans	0.0	0.25-1.0	g/100scf
	H2S	0.0	0.25-1.0	g/100scf
	Total S	0.0	41779	g/100scf
	H2O	0.0	7.00	lbs/mmcf
	O2	0.0	0.2 - 1.0	ppmv

Figure 3.7: Connecting Pipeline to Cove Point Facility

3.4.4 Feed to Cove Point

The feed to Cove Point is based on the details outlined in Step 3 above. Based upon estimates of conditions in the pipeline at the location of delivery the feed pressure and temperature will be 750 psia and 100F, at a flow rate of 750 MMscfd.

Ideally the plant will be built in a robust manner so that it can handle the variable feed possible with the minimum and maximum compositions coming in from the pipeline. Initial designs will be built around the average basic composition of natural gas coming from the Marcellus Shale and being transported in the Mid-Atlantic pipeline.

Table 3.3: Average Basic Composition of Natural Gas from Marcellus Shale

Component:	(mass %)
C1	95.5%
C2	3.0%
C3	1.0%
C4 +	0.0%
CO_2	0.3%
N_2	0.2%
Hg	0.0%
H_2S	0.0%
SO_2	0.0%
S	0.0%
Total	**100%**

3.4.5 Pre-Treatment

After the natural gas is fed into the facility it may need to be pre-treated before entering the specific liquefaction process. The liquefaction process is going to be cooling the natural gas to significantly lower temperatures and it is likely that certain components at certain composition may freeze or damage equipment at these low temperature. Pre-treatment may include many of the same operations discussed in Step 2 such as condensate removal, dehydration, CO_2 removal, H_2 removal, H_2S removal, and LPG extraction. While the natural gas is treated in Step 2, additional treatment is needed to fully prepare the feed for certain process such as liquefaction where the requirements are more stringent.

3.4.6 Liquefaction

The liquefaction process will be built using the Air Product's APCI C3MR process as a guide, as discussed previously in the innovation map. This process involves a precooling section and a subcooling section. Patent number US 3763658 outlines an example process for this, however it must be modified and adjusted to fit the needs and requirements of this particular plant design. Furthermore, the patent is not as detailed as it could be to fully specify certain parts of the process. The LNG specifications that the product must meet were outlined in Section 3.2.

3.4.7 Storage

There is currently 14.6 BCF of LNG storage capacity at the Cove Point facility. The LNG storage tanks have double containers where the inner container holds the LNG and the outer container stores the insulation material to limit heat transfer between the surroundings and the LNG at -260F. LNG storage tanks above ground are approximately 180 feet tall and 250 feet in diameter. Vapor is allowed to boil off and escape from the tank to maintain a constant temperature and pressure via auto-refrigeration.

3.4.8 Transport

LNG is transported using double hulled ships that are highly insulated to prevent any heating of the LNG. The tanks are roughly 1000 feet long and require a minimum water depth of 40 feet. In the ship the LNG is kept near its boiling point so that it undergoes auto refrigeration. Auto refrigeration is the process whereby some of the LNG vaporizes, thus cooling the liquid. The vaporized gas is removed and can be used to supplement fuel for the tanker.

Figure 3.8: LNG Tanker for Delivery From Cove Point to International Markets

3.5 Assembly of Database (Aspen Simulation Specifications)

Aspen Plus version 8.2 was used for this design project. All simulations built for this project should be run in this version of Aspen Plus to avoid encountering compatibility errors.

In this simulation we are using the Soave-Redlich-Kwong (SRK) equation of state as this is the most accurate EOS to be used for modeling natural gas processes. It is noted that Peng

Robinson is also a very common EOS for hydrocarbon systems. SRK is typically used for light hydrocarbons and natural gas processing especially at low temperatures and high pressures as we will have in this design project. It also handles moderates amount of CO_2, H_2S and H_2 fairly well. Peng Robinson is similar to SRK but perhaps better in the critical region and for CO_2 and H_2S. It also predicts gas-hydrates and CO_2 frost points well.

In our simulation, there were a few key equipment pieces that, while in practice are one single unit, in Aspen need to be modeled using multiple units. The first of these is a kettle heat exchanger which will be discussed in more detail later on in this report. Kettle heat exchangers were modeled by a normal HEATX unit followed by a FLASH unit. Secondly, we have a main cryogenic heat exchanger (MCHE) in our simulation. The MCHE contains both a cold and warm bundle. In the simulation this piece of equipment is modeled by two MHEATX units. The MHEATX unit allows for multiple streams to be incorporated into the heat exchanger design. It also allows for internal zone analysis that is not possible in the ordinary HEATX unit. Internal zone analysis makes it possible to identify pinch points more easily. Lastly, the mixed refrigerant pre-cooling loop contains a multi-stage compressor that was modeled via two COMPR units and two HEATER units.

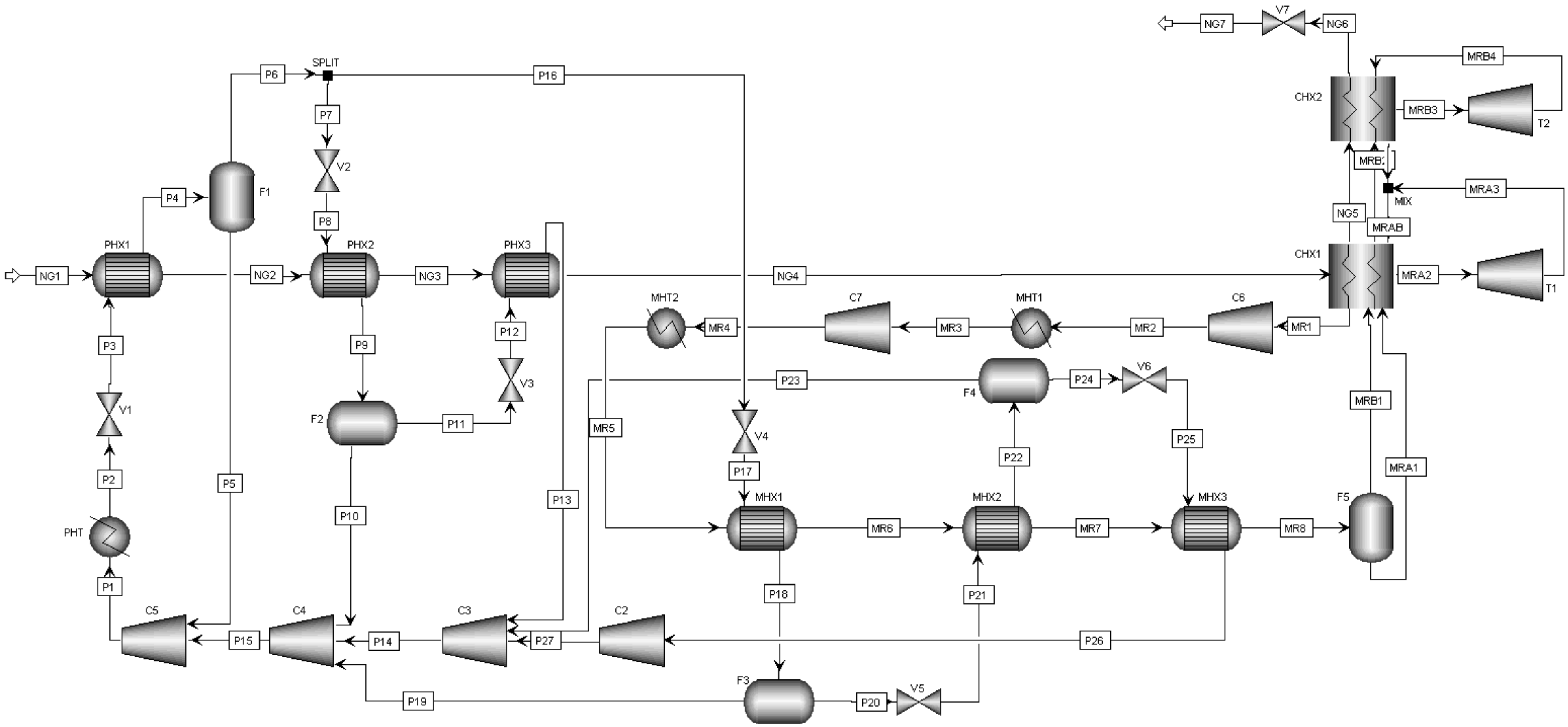
Section 4

Process Flow Diagram &

Material Balances

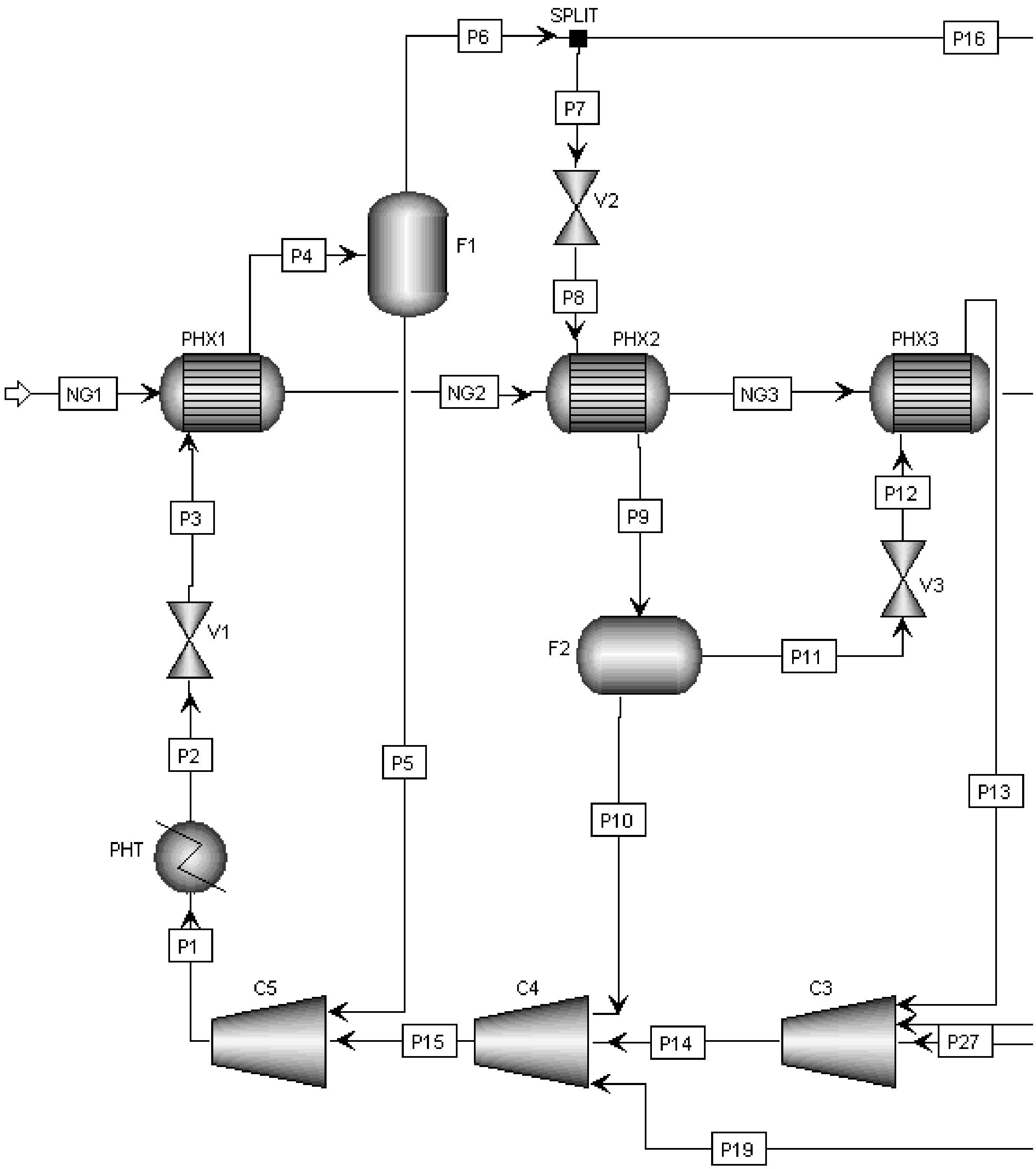
4.1 Overall Process Outline

Figure 4.1: Overall Process Diagram



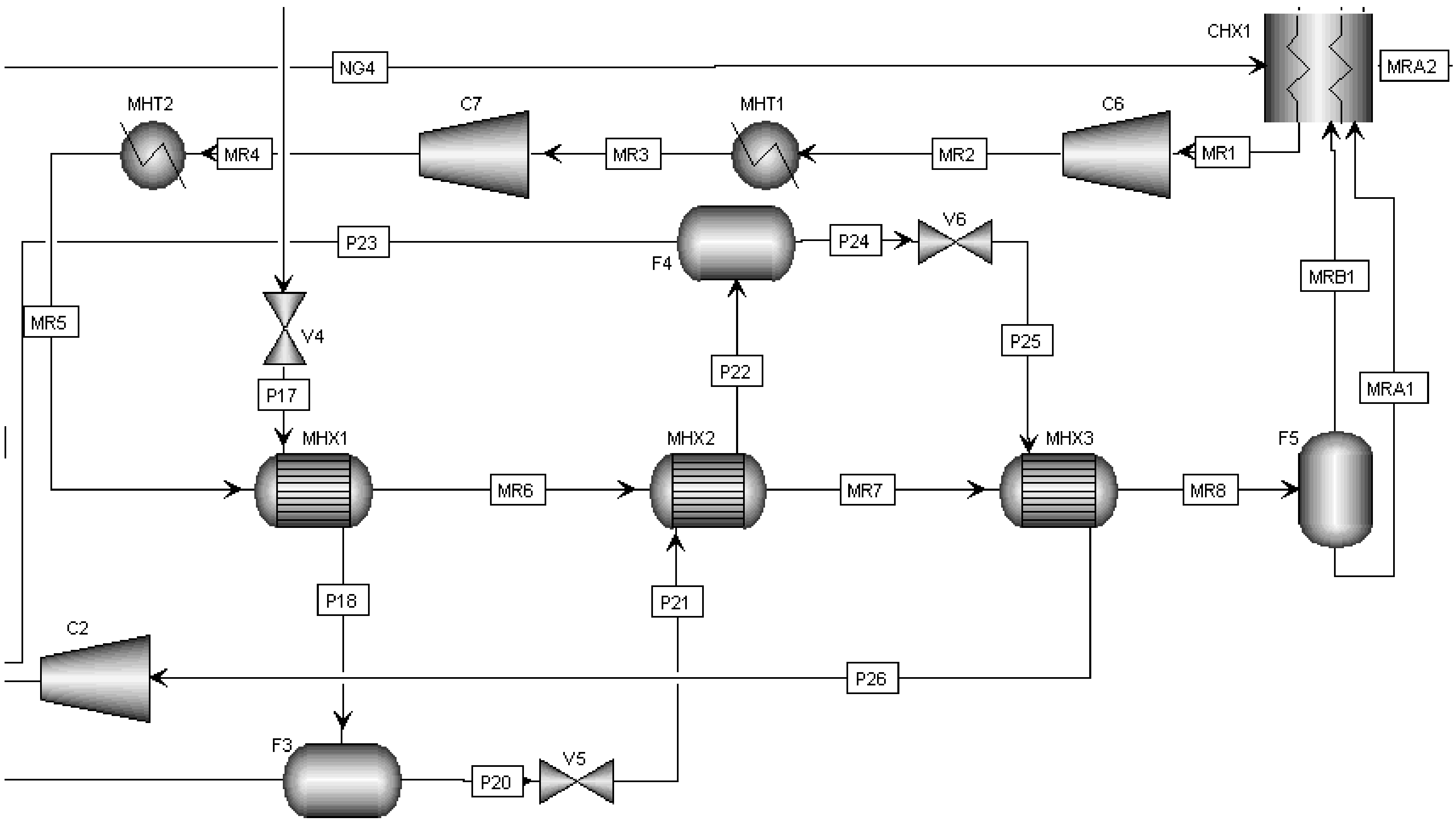
4.2 Propane Pre-Cooling Section

Figure 4.2: Pre-Cooling Process Diagram



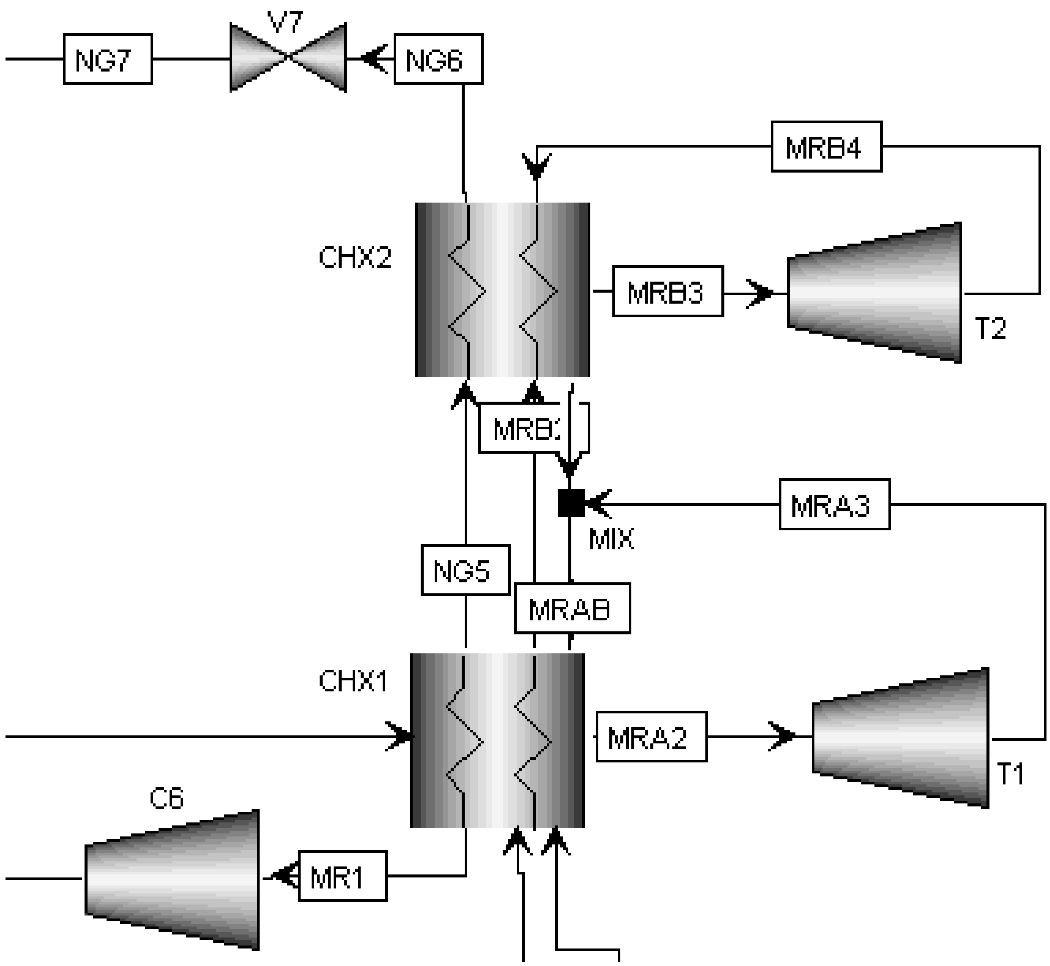
4.3 Mixed Refrigerant Pre-Cooling Section

Figure 4.3: Mixed Refrigerant Pre-Cooling Process Diagram



4.4 Main Cryogenic Heat Exchanger Section

Figure 4.4: Main Cryogenic Heat Exchanger Process Diagram



4.5 Stream Tables

Table 4.1: Feed Natural Gas Streams

Components	**Units**	**NG1**	**NG2**	**NG3**	**NG4**	**NG5**	**NG6**	**NG7**
From		PHX1	PHX2	PHX3	CHX1	CHX2	V7	
To			PHX1	PHX2	PHX3	CHX1	CHX2	V7
Phase		VAPOR	VAPOR	VAPOR	VAPOR	LIQUID	LIQUID	LIQUID
Methane	lbmol/hr	78643.23	78643.23	78643.23	78643.23	78643.23	78643.23	78643.23
Ethane	lbmol/hr	2470.47	2470.47	2470.47	2470.47	2470.47	2470.47	2470.47
Propane	lbmol/hr	823.49	823.49	823.49	823.49	823.49	823.49	823.49
N2	lbmol/hr	0	0	0	0	0	0	0
Total Flow	lbmol/hr	81937.19	81937.19	81937.19	81937.19	81937.19	81937.19	81937.19
Temperature	F	107	70	30	-29	-170	-262	-258.77
Pressure	psia	735	730	725	720	720	720	75
Vapor Frac		1	1	1	1	0	0	0
Liquid Frac		0	0	0	0	1	1	1
Enthalpy	Btu/lbmol	-32382.5	-32759.6	-33175	-33833.1	-37517.9	-38898.6	-38898.6

Table 4.2: Propane Refrigerant Streams

Components	Units	P1	P2	P3	P4	P5	P6	P7	P8	P9
From		PHT	V1	PHX1	F1	C5	SPLIT	V2	PHX2	F2
To		C5	PHT	V1	PHX1	F1	F1	SPLIT	V2	PHX2
Phase		VAPOR	LIQUID	MIXED	MIXED	VAPOR	LIQUID	LIQUID	MIXED	MIXED
Methane	lbmol/hr	0	0	0	0	0	0	0	0	0
Ethane	lbmol/hr	0	0	0	0	0	0	0	0	0
Propane	lbmol/hr	142738	142738	142738	142738	71369.08	71369.08	10705.36	10705.36	10705.36
N2	lbmol/hr	0	0	0	0	0	0	0	0	0
Total Flow	lbmol/hr	142738	142738	142738	142738	71369.08	71369.08	10705.36	10705.36	10705.36
Temperature	F	146.79	100	63.88	63.88	63.88	63.88	63.88	24.97	24.97
Pressure	psia	200	195	115	115	115	115	115	61	61
Vapor Frac		1	0	0.165961	0.198218	1	0	0	0.149432	0.582219
Liquid Frac		0	1	0.834039	0.801782	0	1	1	0.850568	0.417781
Enthalpy	Btu/lbmol	-44340.9	-51273.6	-51273.6	-51057.1	-45676.1	-52387.4	-52387.4	-52387.4	-49208

Components	Units	P10	P11	P12	P13	P14	P15	P16	P17	P18
From		C4	V3	PHX3	C3	C4	C5	V4	MHX1	F3
To		F2	F2	V3	PHX3	C3	C4	SPLIT	V4	MHX1
Phase		VAPOR	LIQUID	MIXED	VAPOR	VAPOR	VAPOR	LIQUID	MIXED	MIXED
Methane	lbmol/hr	0	0	0	0	0	0	0	0	0
Ethane	lbmol/hr	0	0	0	0	0	0	0	0	0
Propane	lbmol/hr	3211.609	7493.753	7493.753	7493.753	49958.36	71369.08	60663.72	60663.72	60663.72
N2	lbmol/hr	0	0	0	0	0	0	0	0	0
Total Flow	lbmol/hr	3211.609	7493.753	7493.753	7493.753	49958.36	71369.08	60663.72	60663.72	60663.72
Temperature	F	24.97	24.97	-34.79	4.94	103.42	132.04	63.88	24.97	24.97
Pressure	psia	61	61	18	18	61	115	115	61	61
Vapor Frac		1	0	0.190428	1	1	1	0	0.149432	0.355614
Liquid Frac		0	1	0.809572	0	0	0	1	0.850568	0.644386
Enthalpy	Btu/lbmol	-46138.9	-53485.1	-53485.1	-46289	-44723.7	-44347.9	-52387.4	-52387.4	-50872.7

Components	**Units**	**P19**	**P20**	**P21**	**P22**	**P23**	**P24**	**P25**	**P26**	**P27**
From		C4	V5	MHX2	F4	C3	V6	MHX3	C2	C3
To		F3	F3	V5	MHX2	F4	F4	V6	MHX3	C2
Phase		VAPOR	LIQUID	MIXED	MIXED	VAPOR	LIQUID	MIXED	VAPOR	VAPOR
Methane	lbmol/hr	0	0	0	0	0	0	0	0	0
Ethane	lbmol/hr	0	0	0	0	0	0	0	0	0
Propane	lbmol/hr	18199.12	42464.6	42464.6	42464.6	12739.38	29725.22	29725.22	29725.22	29725.22
N2	lbmol/hr	0	0	0	0	0	0	0	0	0
Total Flow	lbmol/hr	18199.12	42464.6	42464.6	42464.6	12739.38	29725.22	29725.22	29725.22	29725.22
Temperature	F	24.97	24.97	-34.79	-34.79	-34.79	-34.79	-89.35	-69.97	32.42
Pressure	psia	61	61	18	18	18	18	4	4	18
Vapor Frac		1	0	0.190428	0.930197	1	0	0.15144	1	1
Liquid Frac		0	1	0.809572	0.069803	0	1	0.84856	0	0
Enthalpy	Btu/lbmol	-46138.9	-53485.1	-53485.1	-47490.4	-46924.7	-55028.3	-55028.3	-47395	-45833.7

Table 4.3: Mixed Refrigerant Streams

Components	Units	MR1	MR2	MR3	MR4	MR5	MR6	MR7	MR8
From		C6	MHT1	C7	MHT2	MHX1	MHX2	MHX3	F5
To		CHX1	C6	MHT1	C7	MHT2	MHX1	MHX2	MHX3
Phase		VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	MIXED	MIXED
Methane	lbmol/hr	63000	63000	63000	63000	63000	63000	63000	63000
Ethane	lbmol/hr	51500	51500	51500	51500	51500	51500	51500	51500
Propane	lbmol/hr	22300	22300	22300	22300	22300	22300	22300	22300
N2	lbmol/hr	16908	16908	16908	16908	16908	16908	16908	16908
Total Flow	lbmol/hr	153708	153708	153708	153708	153708	153708	153708	153708
Temperature	F	-57.87	167.81	150	228.81	107	65	16	-27
Pressure	psia	49	350	345	615	611	606	601	596
Vapor Frac		1	1	1	1	1	1	0.734133	0.482774
Liquid Frac		0	0	0	0	0	0	0.265867	0.517226
Enthalpy	Btu/lbmol	-33225.6	-30981.7	-31207.1	-30361.5	-32057.7	-32655.5	-34311.7	-35787.8

Components	Units	MRA1	MRA2	MRA3	MRAB	MRB1	MRB2	MRB3	MRB4	MRB5
From		CHX1	T1	MIX	CHX1	CHX1	CHX2	T2	CHX2	MIX
To		F5	CHX1	T1	MIX	F5	CHX1	CHX2	T2	CHX2
Phase		LIQUID	LIQUID	MIXED	MIXED	VAPOR	LIQUID	LIQUID	MIXED	MIXED
Methane	lbmol/hr	20201.15	20201.15	20201.15	63000	42798.85	42798.85	42798.85	42798.85	42798.85
Ethane	lbmol/hr	38303.08	38303.08	38303.08	51500	13196.92	13196.92	13196.92	13196.92	13196.92
Propane	lbmol/hr	20391.04	20391.04	20391.04	22300	1908.96	1908.96	1908.96	1908.96	1908.96
N2	lbmol/hr	2592.19	2592.19	2592.19	16908	14315.81	14315.81	14315.81	14315.81	14315.81
Total Flow	lbmol/hr	81487.46	81487.46	81487.46	153708	72220.54	72220.54	72220.54	72220.54	72220.54
Temperature	F	-29	-170	-188.58	-192.61	-29	-170	-262	-267.58	-198.70
Pressure	psia	600	600	49	49	600	600	600	51	51
Vapor Frac		0	0	0.110423	0.400565	1	0	0	0.035325	0.72647
Liquid Frac		1	1	0.889577	0.599435	0	1	1	0.964675	0.27353
Enthalpy	Btu/lbmol	-42522.9	-45261.8	-45348.1	-38563.1	-28337.1	-32426.1	-33849.1	-33896.9	-30907.5

Section 5

Process Description

5.1 Overall Process Description

The natural gas feed enters the process in stream NG1, after having had carbon dioxide and other impurities removed during pre-treating in an acid gas removal unit (AGRU), the design of which was outside the scope of this project. Stream NG1 enters the first heat exchanger PHX1 in the propane pre-cooling system a temperature of 107°F and pressure of 735 psia and is then cooled to a temperature of 70°F. We assumed a pressure drop of 5 psia in each of the precooling heat exchangers.

The natural gas stream leaves PHX1 as stream NG2 and enters a second single-component refrigerant heat exchanger PHX2 in which the natural gas is cooled to approximately 30°F. The cooled natural gas stream NG3 is then passed to a third single component refrigerant heat exchanger PHX3, in which it is cooled to approximately -29°F.

The natural gas stream NG4 then moves into tube circuit NG5 of the two-zone main cryogenic heat exchanger (CHX1, CHX2). The multicomponent refrigerant portion of the cycle will be described in further detail in Section 5.4. The natural gas passes upwardly through tube circuit NG5 and is cooled by the counter-flow of a first multicomponent refrigerant fraction sprayed downwardly over the tube bundle from spray header MRAB. The natural gas stream NG5 is cooled to approximately -170°F before entering a second tube circuit NG6 in the second zone of the heat exchanger (CHX2), passing upwardly through the tube circuit while being cooled by a second counterflowing multicomponent refrigerant fraction sprayed downwardly through MRB4. Stream NG6 exits the top of the tube circuit as a completely liquid and subcooled stream having a temperature of -262°F and a pressure of 720 psia. The liquefied and deeply subcooled natural gas stream is then expanded in valve V7 to a pressure of 75 psia and a temperature of approximately -259°F. Due to the deep subcooling, no flash occurs and the liquid stream NG7 may be delivered directly to a storage tank in which it may be stored at atmospheric pressure and a temperature of -259°F.

5.1.1 Use of Cold Vapor Streams in Process

In designing this process, the team worked to use the full cooling capacity of the refrigerant streams to cool the natural gas; however, there are some instances in the process in which this is not done. For example, there is still useful cooling capacity in the vapor propane streams that leave the heat exchangers in the natural gas pre-cooling loop. There exist certain tradeoffs when deciding whether to contact the cold propane stream with the warm natural gas. First, the propane is sent to a compressor after exiting the heat exchanger, and this compressor operates more efficiently at colder temperatures. As a result, there is some benefit to feeding cool refrigerant into the unit rather than a warmer stream that has absorbed more heat from the natural gas. In addition, as more heat is absorbed by the refrigerant, more energy is required to compress the refrigerant so that it can continue working in the cycle. Lastly, capital expenditures would increase with purchasing additional equipment, such as additional heat exchangers, to utilize all the cooling capacity of the refrigerant streams. These additional expenditures are not justified by the small potential efficiency gains. It is also worth noting that the major workhorse of this process is the main cyrogenic heat exchanger, in which most of the heat exchange takes place. Any efficiency losses in the pre-cooling steps are minimal compared to that of the MCHE.

5.1.2 Three Pre-Cooling Heat Exchangers

Each of the heat exchangers in the natural gas pre-cooling section operates at a different pressure, and consequently different temperatures, with each subsequent heat exchanger operating at a lower temperature than the previous one. The two primary reasons for using this design are capital efficiency and technical feasibility. Ideally, using one piece of equipment would be the cheapest way to design the process, as more work is done per dollar invested. However, it is not technically feasible to achieve the necessary amount of pre-cooling in a single kettle heat exchanger. Kettle heat exchangers, similar to shell and tube exchangers, have a certain maximum size for their design, and one of these heat exchanger would be far too large for the amount of cooling required. Depending on the size of the plant, either two or three heat exchangers can be used. For this 5-6 MTPA plant, three heat exchangers are optimal.

5.2 Propane Pre-Cooling Description

Referring back to heat exchangers PHX1, PHX2 and PHX3, the propane refrigerant is compressed in a series of four compressors having stages C1, C2, C3 and C4. The compressed propane is cooled and completely condensed in water cooler PHT, and is then expanded in valve V1 before entering heat exchanger PHX1 at a temperature of approximately 64°F and pressure of 115 psia. The heat exchangers in the propane pre-cooling system are kettle heat exchangers. Thus, a portion of the liquid propane is vaporized while cooling the natural gas stream on the tube side, and this vapor is returned through stream P5 to compressor C4. The remaining refrigerant in the liquid phase from exchanger PHX1 leaves as stream P6 and is split into liquid streams P7 and P16. The liquid propane in stream P7 is expanded by valve V2 to a pressure of 61 psia before entering heat exchanger PHX2 at a temperature of approximately 25°F. A portion of the refrigerant is vaporized in cooling the natural gas stream in exchanger PHX2 and is returned through stream P10 to the suction side of compressor C3. The remaining liquid propane from exchanger PHX2 leaves as stream P11, is expanded in valve V3 to a pressure of 18 psia, and is then introduced into exchanger PHX3 at a temperature of approximately 5°F. All of the refrigerant entering exchanger PHX3 in stream P12 is vaporized in cooling the natural gas stream, and the refrigerant vapor is returned through stream P13 to the suction side of compressor C2. Thus, the natural gas stream is progressively cooled in three single-component refrigerant heat exchangers using liquid propane at decreasing pressures and temperatures in a three-stage, cascade refrigerant cycle, a commonly used strategy in liquefaction processes.

5.3 Mixed Refrigerant Pre-Cooling Description

The propane refrigerant used in the propane pre-cooling system is also involved in cooling and partially condensing the multicomponent refrigerant used to liquefy and subcool the natural gas stream in the main cryogenic heat exchanger. The multicomponent refrigerant is cooled by the second portion of the liquid propane from PHX1 in stream P16 in heat exchangers MHX1, MHX2 and MHX3. The liquid propane in stream P16 is expanded through valve V4 to a pressure of 61 psia and enters exchanger MHX1 at a temperature of approximately 25°F. Exchanger MHX1 is of a kettle design in which some of the propane is vaporized and leaves in stream P19 to return to the suction side of compressor C3. The remaining liquid propane leaves through stream P20 to be expanded through valve V5 to a pressure of 18 psia and a temperature of approximately -35°F before entering exchanger MHX2. A portion of the propane is vaporized while cooling the multicomponent refrigerant, and this portion returns to the suction side of compressor C2 as stream P23. The remaining liquid portion of the propane exits in stream P24 and is expanded through valve V6 to a pressure of 4 psia, after which it enters MHX3 at a temperature of approximately -89°F. The propane is completely vaporized while partially condensing the multicomponent refrigerant, and then returns to the suction side of compressor C1 as stream P26. Thus, the propane refrigerant system comprises a closed cycle in which the natural gas stream is cooled by the propane in exchangers PHX1, PHX2 and PHX3 while the multicomponent refrigerant is partially condensed in propane exchangers MHX1, MHX2 and MXH3.

5.4 Main Cryogenic Heat Exchanger Description

The natural gas entering the two-zone main cryogenic heat exchanger in stream NG4 is cooled by the mixed refrigerant leaving the pre-cooling cycle. The liquid condensate in flash separator F5 is passed to tube circuit MRA1 of the warm bundle of the heat exchanger, CHX1, in which it is subcooled to a temperature of approximately -170°F. This subcooled liquid is expanded in turbine T1 to a pressure of 49 psia. A small portion flashes to vapor, and the temperature of the mixture drops to -189°F. The liquid and flashed vapor are injected into exchanger zone CHX1 via stream MRAB through a spray header to provide refrigerant flowing downwardly over tube circuits MRA1, MRB1 and NG4. The spray header is designed for uniform distribution of the multicomponent liquid and flashed vapor mixture over the tube circuits, and results in a slight pressure decrease when the stream exits the spray header.

Referring back to phase separator F5, the overhead vapor has a composition of approximately 20 mole percent nitrogen, 59 mole percent methane, 18 mole percent ethane, and 3 mole percent propane. This vapor passes to tube circuit MRB1 in which the vapor is cooled and condensed by the downwardly sprayed refrigerant fraction described in the previous paragraph. The condensed multicomponent refrigerant in tube circuit MRB1 passes directly into a second tube circuit MRB2, in which it is subcooled to a temperature of -262°F. This subcooled liquid fraction is expanded in turbine T2 to a pressure of 51 psia. A small fraction is flashed to vapor, and the temperature drops to approximately -268°F. The liquid and flashed vapor are injected into the cold bundle of the heat exchanger, CHX2, via stream MRB4 through a spray header to provide downwardly flowing refrigerant over the tube circuits MRB2 and NG5. In flowing downwardly over these two tube circuits, the multicomponent liquid fraction from the spray header is vaporized and thereby subcools both the feed stream in circuit NG5 and the multicomponent liquid fraction in circuit MRB2. Similarly, the multicomponent liquid fraction sprayed from the spray header in heat exchanger zone CHX1 is vaporized in heat exchange with tube circuits MRA1, MRB1 and NG4. As a result, all of the multicomponent refrigerant is recombined in the vapor phase at the bottom of heat exchanger zone CHX1 and is withdrawn and passed through stream MR1 to the suction side of compressor C5. Thus, the multicomponent refrigerant portion of the system forms a separate closed cycle whereby the feed stream is cooled most efficiently from the propane level down to the final subcooled temperature of -262°F.

5.4.1 Mixed Refrigerant Analysis:

The mixed refrigerant composition can be strategically selected so as to maximize the efficiency of the main cryogenic heat exchanger in the liquefaction process. Theoretically, the study of the impact of the mixed refrigerant on the MCHE is complex and very tedious to analyze.[11] However, with a functioning model built in Aspen Plus, sensitivities can be performed to determine, for this given process, what the ideal composition would be.[12] The heating and cooling curves for the MCHE are very important not only in identifying feasibility but also examining optimization results for heat transfer in the unit. This analysis was conducted by iteratively changing the mixed refrigerant composition.

[11]Mohd Zaki Zainal Abidin et al. "**Effect of Varying Mixed Refrigerant Composition on Main Cryogenic Heat Exchanger Performance**." *Key Engineering Materials*.594-595 (2013): 13. Web.
[12] Helgestad, Dag-Erik. *Modelling and Optimization of the C3MR Process for Liquefaction of Natural Gas*. KP 4550 Process Systems Engineering, 2009. Print.

Table 5.1: Tested Variations of Mixed Refrigerant Composition

Components (mol %)	C1	C2	C3	N2
Min	35%	39.5%	14.5%	11%
Base	**41%**	**33.5%**	**14.5%**	**11%**
Max	44%	30.5%	14.5%	11%

Figure 5.1: Heating and Cooling Curves for Warm Bundle of MCHE, Base Case

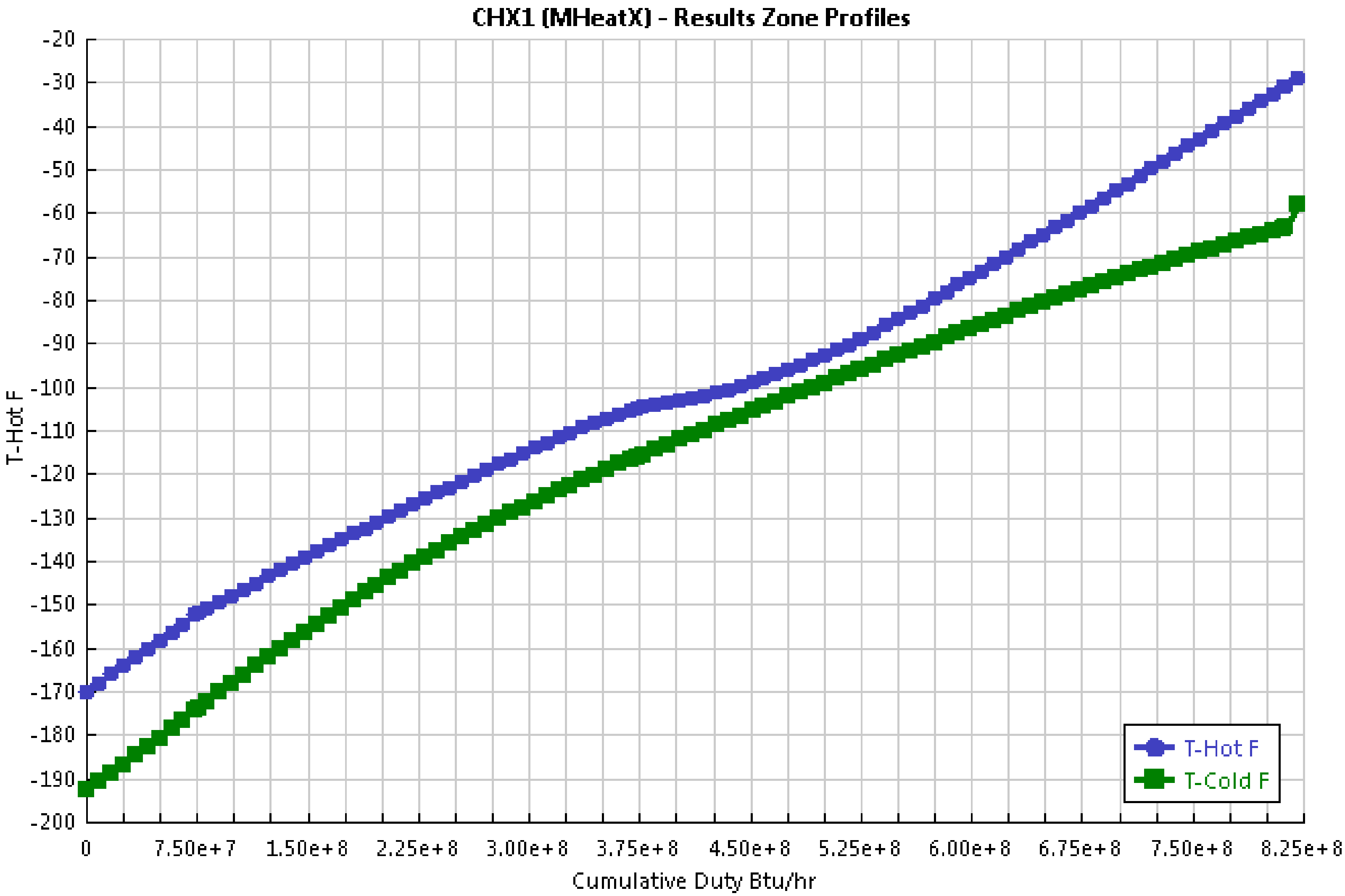


Figure 5.2: Heating and Cooling Curves for Cold Bundle of MCHE, Base Case

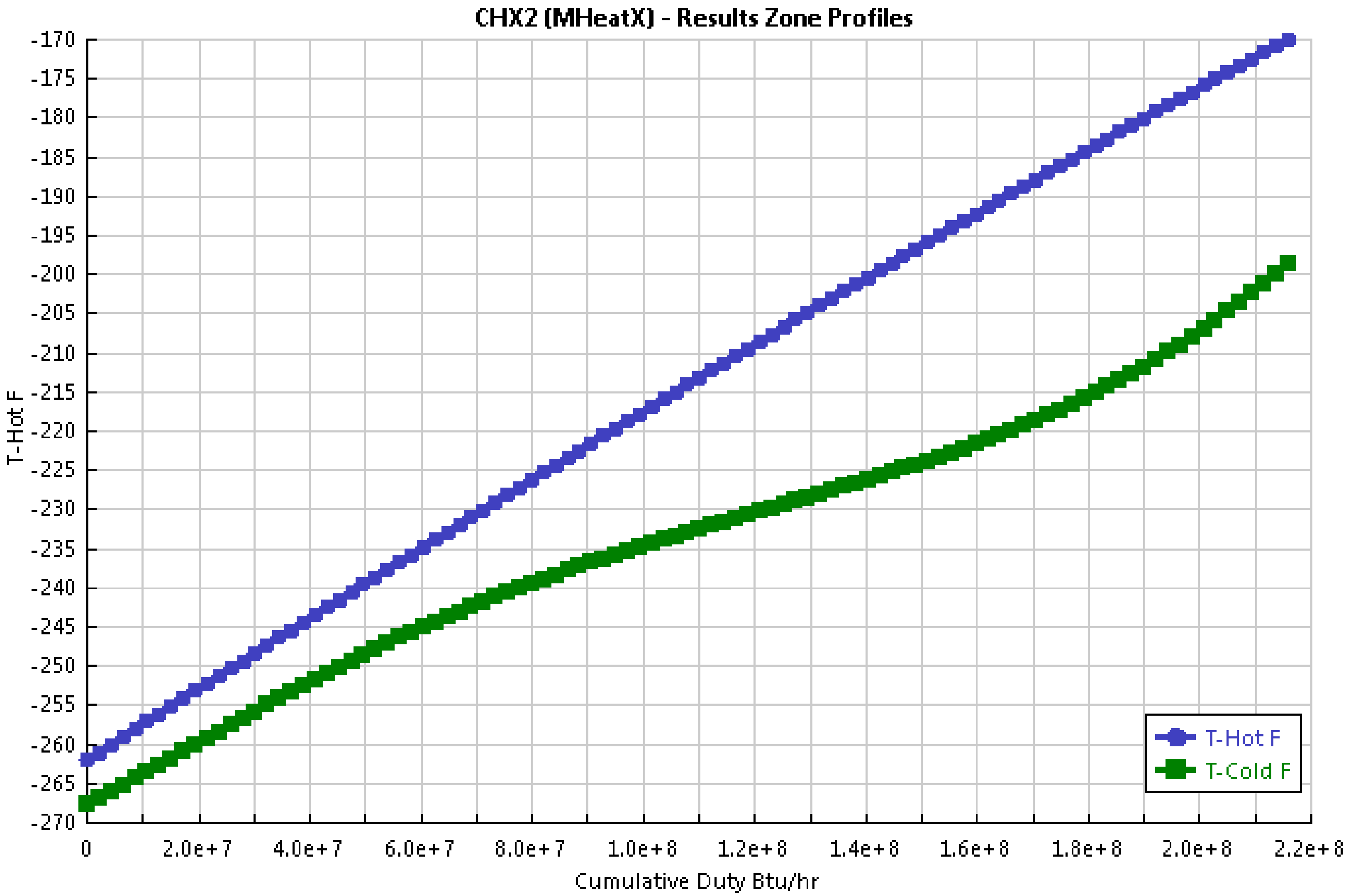


Figure 5.3: Heating and Cooling Curves for Warm Bundle of MCHE, Min Case

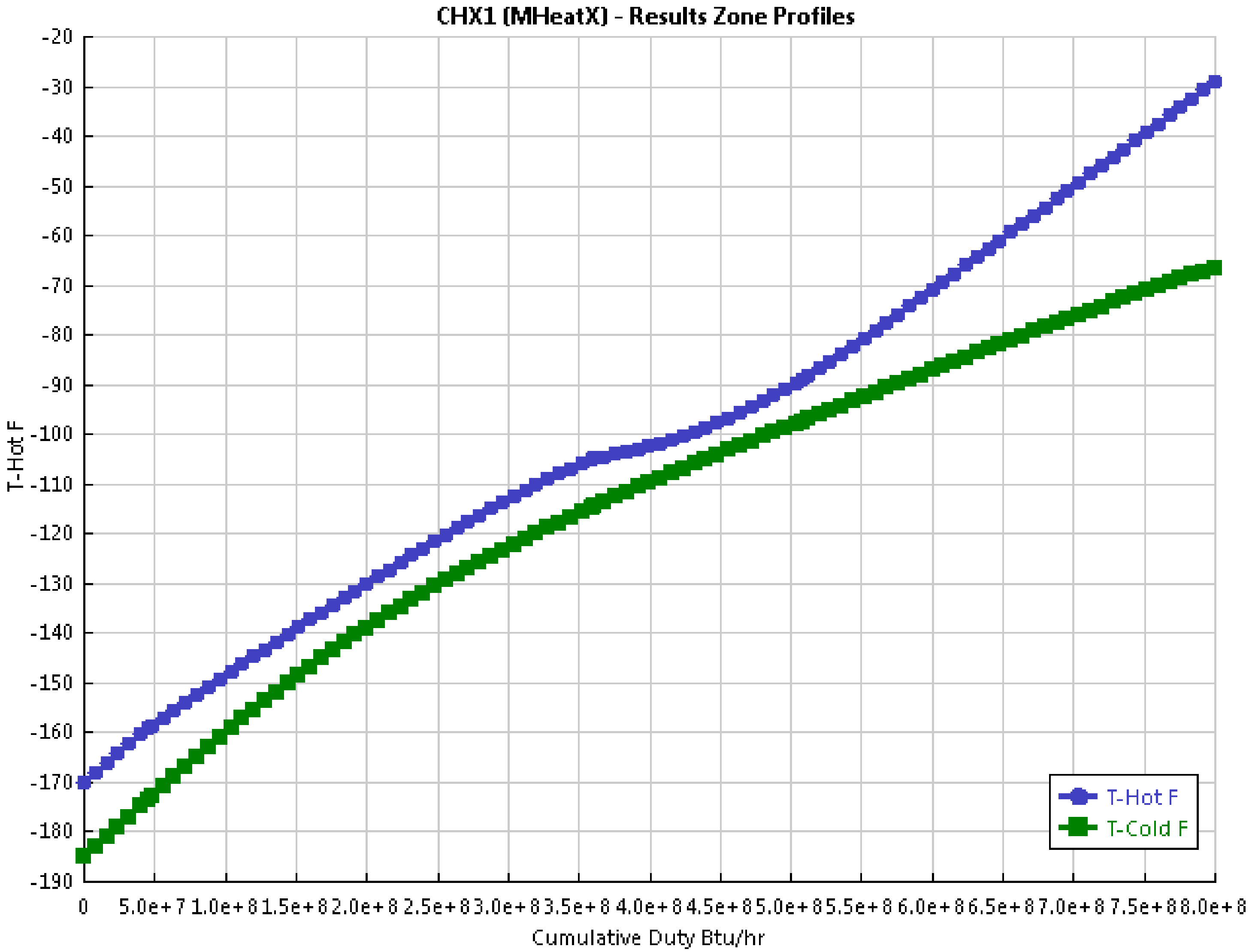


Figure 5.4: Heating and Cooling Curves for Cold Bundle of MCHE, Min Case

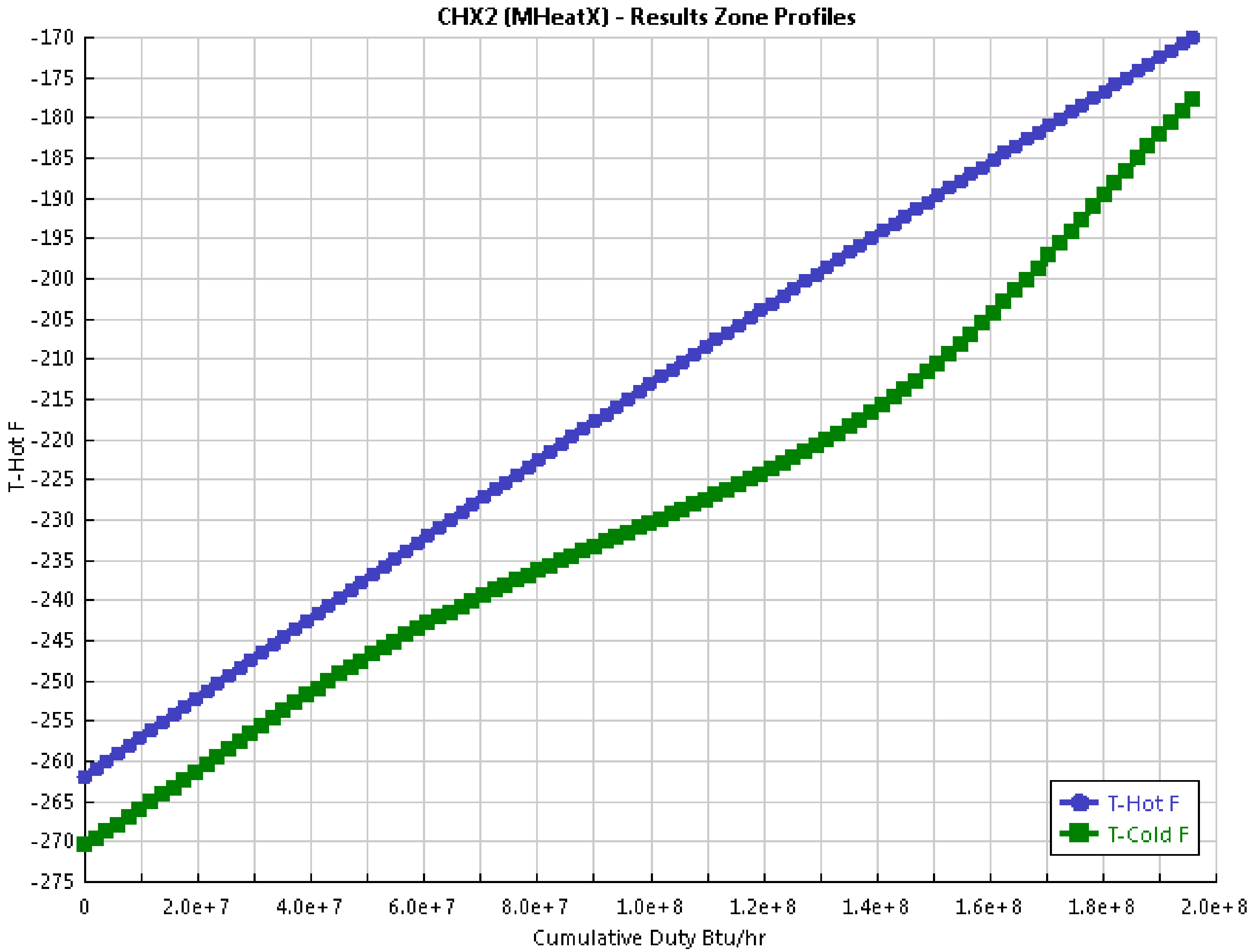


Figure 5.5: Heating and Cooling Curves for Warm Bundle of MCHE, Max Case

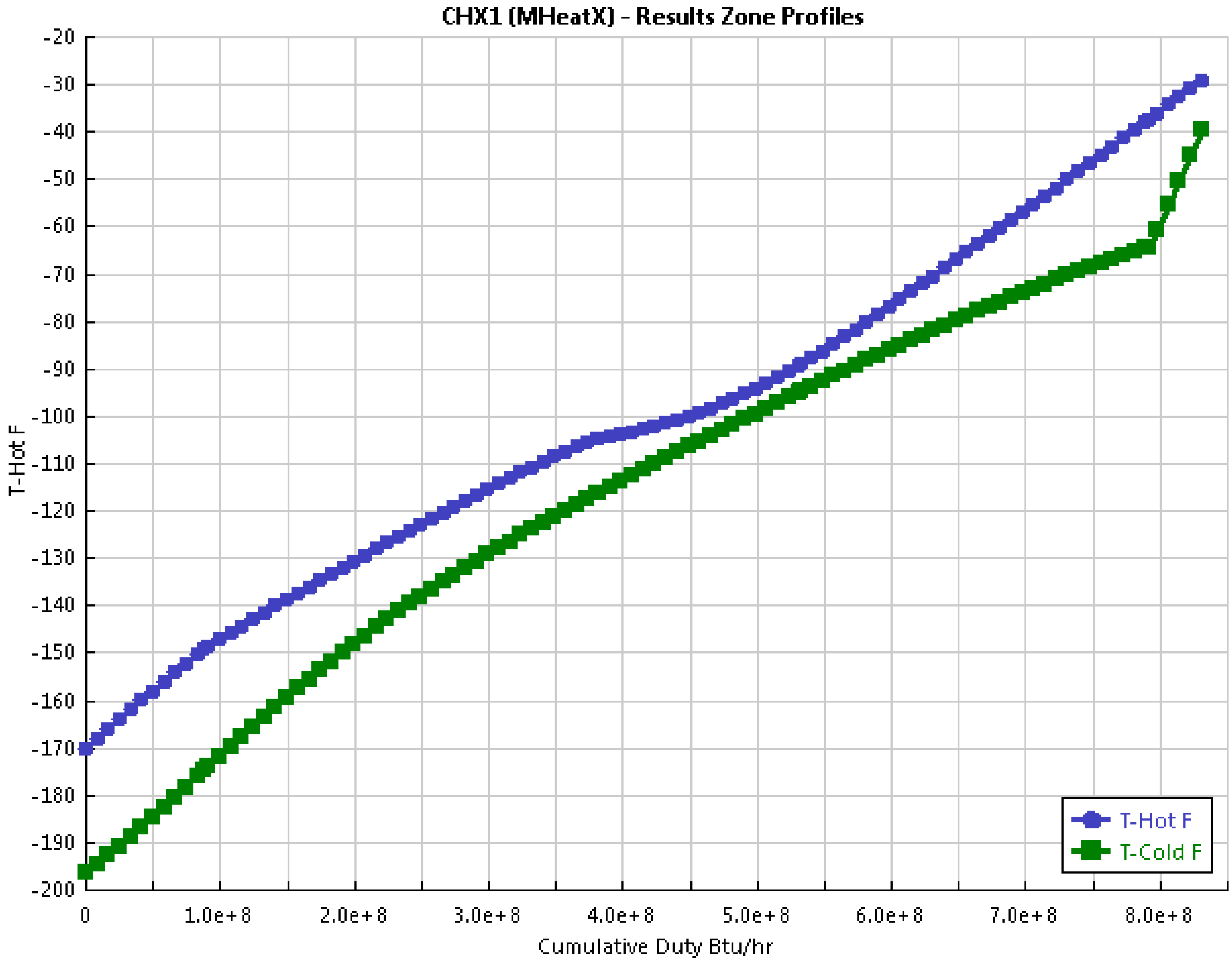
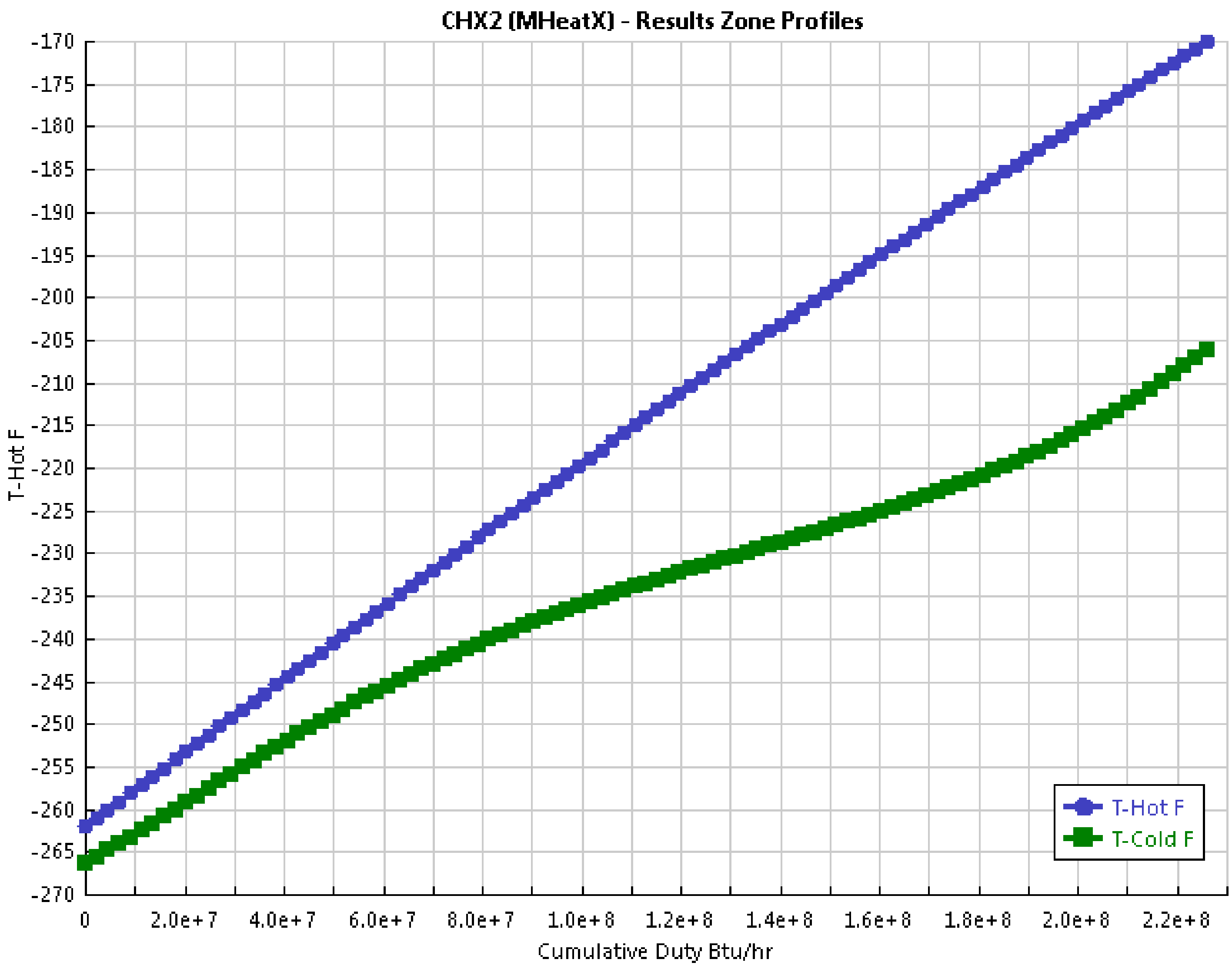


Figure 5.6: Heating and Cooling Curves for Cold Bundle of MCHE, Max Case



5.5 Pre-Liquefaction Steps

5.5.1 Acid Gas Removal Unit (AGRU)

Any cryogenic gas separation process requires the treatment of the gas upstream to remove H2S, CO2 and organic sulfurs such as mercaptan and COS that can be present in the incoming natural gas stream into the LNG liquefaction plant. These components are removed for the LNG to meet required market standards and specifications. An AGRU is installed to clean this stream to a suitable composition to enter the liquefaction part of the plant. The most common way to accomplish this is for amine to counter-currently contact the natural gas inside an absorber (scrubber) column. The hazardous acid gas substances are absorbed by the amine for treatment. This is a 'wet' process and therefore a dehydration process is needed at a later stage, usually accomplished by molecular sieve. While an ARGU was not specifically designed for this plant as the liquefaction step was the main focus, a standard ARGU is assumed to be built and the cost of this unit is approximated for purposes of estimating the project economics. The cost is lumped into the pre-treatment cost for the economic analysis in Section 10.

5.5.2 LPG Extraction

Before entering the liquefaction process, liquefied petroleum gas (LPG) consisting of ethane, propane and butane, is extracted from the natural gas feed stream, which modifies the heating value at the liquefaction end. LPG extraction can be performed by a variety of different processes. One of the most common ways to perform LPG extraction is through turbo-expander extraction.[13] The key feature of this technique is a dynamic expansion of the natural gas followed by re-compression, this produces liquids for the LPG. The expansion follows an isentropic path

[13] Honeywell UOP. "**Gas & LPG Treating**." 2014.Web. <http://www.uop.com/processing-solutions/refining/gas-lpg-treating/>.

thermodynamically which leads to high efficiencies for the process in contrast to a static expansion through a valve which would be much more isenthalpic. It is important that these heavy components are removed before entering the main liquefaction process so that the final LNG can be meet product standards but, perhaps more importantly, so the heavies in the actual process natural gas that moves on from this section do not freeze in the main cryogenic heat exchanger. It is also noted that LPG removal can also be accomplished using scrub columns at varying temperatures, but this is often more expensive. The costing of the LPG extraction unit is also grouped into a general pre-treatment cost as discussed above in the section for the AGRU unit.

Section 6

Unit Descriptions & Equipment Lists

6.1 Unit Descriptions

6.1.1 Main Cryogenic Heat Exchanger

The main cryogenic heat exchanger (MCHE) is a critical piece of equipment in a liquefaction process. The design of the MCHE is proprietary and very little detailed information exists in the public domain, thus making it difficult to accurately model. There are two main styles of heat exchangers to choose between: spiral wound exchangers (SWHEs) in pressurized shell and plate-fin exchangers (PFHEs) in a cold box. There is little difference in cost and schedule between the two designs. The plate-fin exchangers are more compact and are typically used when there are multiple process streams involved in the MCHE (up to 10 streams can be incorporated). The PFHE features a stack of alternating flat and corrugated plates whereby the corrugations (fins) form the flow channels for the diverse process fluids. A SWHE design contains helically wound tube bundles housed within an aluminum or stainless steel pressurized shell designed to retain refrigerants in the event of a shutdown. It consists of anywhere from one to three coil wound bundles each made up of several tube circuits all within the shell. The tubes are wound in a helical fashion around a long hollow aluminum tube. The entire bundle is enclosed within a shroud and supported from the mandrel and the shell. Each tube bundle is wrapped into a shroud which is seal welded on the upper side of the shell to avoid any refrigerant passing between the tube bundle and the shell. A spiral wound heat exchanger has been selected for the MCHE in this process design because of its robustness. It is a very popular choice of heat exchanger that is functional at a wide range of design temperatures, temperature gradients and temperature differences.

Table 6.1: Comparison between PFHEs and SWHEs

Characteristic	**PFHE's**	**SWHE's**
Features	Extremely compact Up to 10 process streams	Extremely robust Compact
Heating Surface	300 - 1000 m2/m3	50 - 150 m2/m3
Materials	Aluminum alloys 3003 and 5083	Al, SS, Cs
Design Temperatures	-269C to +65C	All
Applications	Smooth operation Limited installation space	High temperature gradients Larger temperature differences

6.1.2 Kettle Heat Exchangers

Kettle heat exchangers are commonly used when a wide range of process operations or large heat exchanger surfaces are required in a process. Kettles are often more costly than ordinary heat exchangers due to large shell sizes.

In a kettle heat exchanger, the cold fluid typically enters through the bottom of the shell and forms a pool. Hot fluid flows through tubes that are submerged in the cold pool. The cold liquid absorbs energy from the warm fluid and vaporizes, exiting as a vapor stream through the top of the shell. Unvaporized cold fluid exits through the bottom of the shell. Heat transfer occurs by two methods of convection: liquid-free convection and rising gas convection. Liquid-free convection is caused by the density difference in the cold fluid pool, which occurs as warm shell-side fluid rises and is replaced by cooler denser fluid. As the shell-side fluid absorbs heat and begins to vaporize, it forms bubbles that grow in size and rise through the tube bundle. Cooler shell-side fluid flows down around the tube bundle, replacing the warm fluid while creating a convection effect. The rising air bubbles also create a secondary convection effect.

The kettle heat exchanger is designed to vaporize the cold fluid in the shell side. Due to such a design, optimal heat transfer occurs when the cold fluid enters the heat exchanger at near-boiling conditions. If the cold fluid requires a large sensible duty to bring it to boiling conditions before vaporization, the heat transfer is negatively affected.

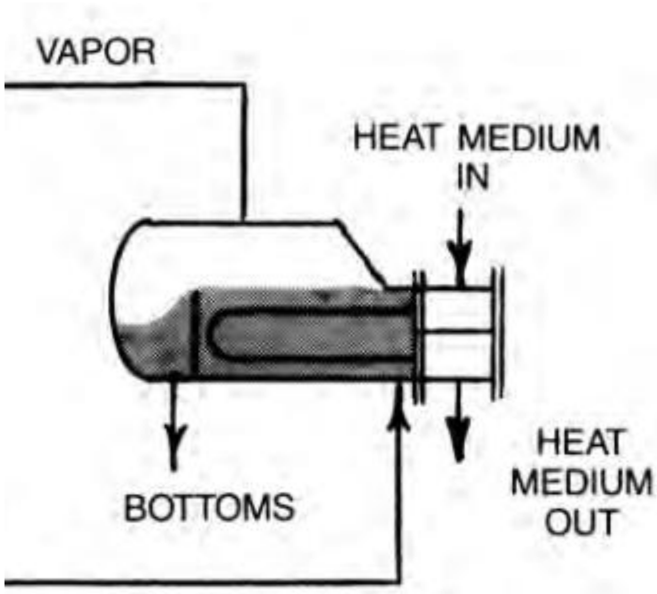


Figure 6.2: Simplified Model of Kettle Heat Exchanger

6.1.3 Turbines

Many chemical processes require a step that significantly decreases pressure. Pressure drops occur when fluids are expanded, either to release to atmosphere or to induce a temperature reduction. While valves can be used to facilitate this pressure drop, turbines offer another advantage in their ability to capture work from the fluid expansion.

In this liquefaction process, turbines are used in conjunction with the main cryogenic heat exchanger (MCHE). The mixed refrigerant is expanded in both the warm bundle and the cool bundle before being sprayed down the MCHE. In both cases, a significant pressure drop occurs. Here the turbines are used to stabilize the process rather than capture useful work from the pressure expansion. When expanding through the turbine, the liquid mixed refrigerant (MR) partially vaporizes, leaving the turbine as a mixed vapor and liquid phase. This significant increase in fluid volume can potentially destabilize the expander, thus requiring a turbine instead of a standard Joule-Thomson valve. As a secondary consideration, any energy generated by these turbines can be harvested and used in other areas of this process.

6.1.4 Valves

Valves can be used to expand fluids at a relatively low cost. Expansion through a valve occurs by isenthalpic throttling and follows the Joule-Thomson effect.

6.1.5 Compressors

Compressors are used throughout the process to increase the pressures of the vapor propane coolant and the mixed refrigerant. A coolant stream vaporizes when removing heat from feed streams. The vapor coolant then enters a compressor and exits as a vapor at a higher pressure. Compressors are often combined with a subsequent cooler in order to return a hot vapor to a cold liquid form.

Compressors fall into three categories: positive displacement, dynamic, or thermal. Positive displacement compressors consist of reciprocating and rotary types, both of which increase gas pressure by displacing a certain volume of gas. Dynamic compressors (rotary) include radial flow (centrifugal), axial flow, and mixed flow compressors, all of which use rotating blades or impellers to increase the fluid's pressure as the fluid moves through the compressor. These rotary compressors convert the inlet stream's velocity head into static pressure. Thermal compressors include ejectors that use a high velocity stream to carry along the desired fluid and increase its pressure.

Multi-stage centrifugal compressors were selected to meet this project's specifications. Centrifugal compressors offer several advantages compared to reciprocating compressors: lower maintenance cost, longer useful life, and greater capacity per land area.

6.2 Unit Equipment Lists

Table 6.2: List of major equipment and associated costs

Equipment	Type	Purchase Cost	Bare Module Cost
C1	Compressor	$ 2,883,652	$ 7,023,192
C2	Compressor	$ 4,132,290	$ 10,064,275
C3	Compressor	$ 3,404,929	$ 8,292,772
C4	Compressor	$ 5,149,030	$ 12,540,566
C5	Compressor	$ 14,348,426	$ 34,945,878
C6	Compressor	$ 6,572,720	$ 16,007,991
T1	Turbine	$ 359,055	$ 874,485
T2	Turbine	$ 218,319	$ 531,720
PHX1	Kettle Exchanger	$ 115,381	$ 1,117,529
PHX2	Kettle Exchanger	$ 128,315	$ 1,274,963
PHX3	Kettle Exchanger	$ 150,727	$ 1,555,209
MHX1	Kettle Exchanger	$ 111,550	$ 1,071,203
MHX2	Kettle Exchanger	$ 235,666	$ 2,680,864
MHX3	Kettle Exchanger	$ 180,775	$ 1,943,020
MHT1	Cooler	$ 33,437	$ 125,071
MHT2	Cooler	$ 147,070	$ 586,245
PHT1	Cooler	$ 1,566,949	$ 8,142,693
CHX1	Spiral Wound Exchanger	$ 22,361,412	$ 447,877,647
CHX2	Spiral Wound Exchanger	$ 3,331,847	$ 50,352,335
Total		**$65,431,548.90**	**$ 607,007,658.76**

6.2.1 Compressors

To ensure reliability, each compression step in the process is run in parallel with two 50% compressors. Sizing and costing sample calculations for key equipment units are shown in Appendix C.

C1 - Purchase Cost: $2,883,652

This is a carbon steel compressor used to compress P26 to 18 psia, and is the first compressor in a compressor train returning propane from vapor to liquid phase. The isentropic efficiency is assumed to be 0.81. The flow rate through the compressor is 1,310,780 lb/hr. The brake power required for the compressor is 9,120 hp.

C2 - Purchase Cost: $4,132,290

This is a carbon steel compressor used to compress P13, P23, and P27 to 61 psia, and is the second compressor in a compressor train returning propane from vapor to liquid phase. The isentropic efficiency is assumed to be 0.81. The flow rate through the compressor is 2,202,990 lb/hr. The brake power required for the compressor is 14,299 hp.

C3 - Purchase Cost: $3,404,929

This is a carbon steel compressor used to compress P10, P14, and P19 to 115 psia, and is the third compressor in a compressor train returning propane from vapor to liquid phase. The isentropic efficiency is assumed to be 0.81. The flow rate through the compressor is 3,147,130 lb/hr. The brake power required for the compressor is 11,225 hp.

C4 - Purchase Cost: $5,149,030

This is a carbon steel compressor used to compress P5 and P15 to 200 psia, and is the fourth and final compressor in a compressor train returning propane from vapor to liquid phase. The isentropic efficiency is assumed to be 0.81. The flow rate through the compressor is 6,294,260 lb/hr. The brake power required for the compressor is 18,824 hp.

C5 - Purchase Cost: $14,348,426

This is a carbon steel compressor used to compress MR1 to 350 psia, and is the first compressor in a compressor train returning the mixed refrigerant from vapor to liquid phase. The isentropic efficiency is assumed to be 0.81. The flow rate through the compressor is 4,016,290 lb/hr. The brake power required for the compressor is 67,774 hp.

C6 - Purchase Cost: $6,572,720

This is a carbon steel compressor used to compress MR3 to 615 psia, and is the second and final compressor in a compressor train returning the mixed refrigerant from vapor to liquid phase. The isentropic efficiency is assumed to be 0.81. The flow rate through the compressor is 4,016,290 lb/hr. The brake power required for the compressor is 25,541 hp.

6.2.2 Heat Exchangers

The overall heat transfer coefficients U (BTU/hr ft^2 °F) were estimated based on the cold and hot stream compositions. Heat exchange between the natural gas and cooling streams was assumed to have a coefficient of 50 BTU/hr ft^2 °F and cooling of propane and mixed refrigerant streams with water was 140 BTU/hr ft² °F. The overall heat transfer coefficient will be smaller in the first situation due to the vapor nature of the natural gas. [14]

CHX 1&2 - Purchase Cost: $138,745,005

The is the carbon steel main cryogenic heat exchanger used to liquefy the precooled natural gas stream NG4 from -29°F to -262°F. It is assumed that the MCHE can be modeled as a shell and tube heat exchanger warm bundle (CHX1) and cold bundle (CHX2). The necessary heat duty is 1,036,320,000 BTU/hr. The surface area is calculated as 1,603,173 ft².

MHT1 - Purchase Cost: $34,829

This cooler is a carbon steel shell and tube heat exchanger used to lower the temperature of mixed refrigerant stream MR2 from 168°F to 150°F. The necessary heat duty is 35,756,161 BTU/hr. The surface area is calculated as 2,956 ft² using cooling water that is heated from 65°F to 79°F on the shell side. The tube side pressure drop is assumed to be 5 psi.

MHT2 - Purchase Cost: $163,255

This cooler is a carbon steel shell and tube heat exchanger used to lower the temperature of mixed refrigerant stream MR4 from 229°F to 107°F. The necessary heat duty is 260,722,140 BTU/hr. The surface area is calculated as 22,992 ft² using cooling water that is heated from 65°F to 79°F on the shell side. The tube side pressure drop is assumed to be 5 psi.

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[14] Perry, Robert, and Donald W. Green. ***Perry's Chemical Engineers' Handbook***. 8th ed. McGraw-Hill Professional, 2007. Print.

MHX1 - Purchase Cost: $298,304

This is a carbon steel kettle heat exchanger used to lower the temperature of mixed refrigerant stream MR5 from 107°F to 65°F. The necessary heat duty is 91,885,171 BTU/hr. The surface area is calculated as 31,456 ft^2 using 25°F propane on the shell side. The tube side pressure drop is assumed to be 5 psi.

MHX2 - Purchase Cost: $746,556

This is a carbon steel kettle heat exchanger used to lower the temperature of mixed refrigerant stream MR6 from 65°F to 16°F. The necessary heat duty is 254,565,705 BTU/hr. The surface area is calculated as 74,056 ft^2 using -35°F propane on the shell side. The tube side pressure drop is assumed to be 5 psi.

MHX3 - Purchase Cost: $541,084

This is a carbon steel kettle heat exchanger used to lower the temperature of mixed refrigerant stream MR7 from 16°F to -27°F. The necessary heat duty is 226,900,396 BTU/hr. The surface area is calculated as 55,595 ft^2 using -89°F propane on the shell side. The tube side pressure drop is assumed to be 5 psi.

PHT - Purchase Cost: $2,267,543

This cooler is a carbon steel kettle heat exchanger used to lower the temperature of propane stream P1 from vapor at 148°F to liquid at 100°F. The necessary heat duty is 989,561,416 BTU/hr. The surface area is calculated as 228,949 ft^2 using cooling water that is heated from 65°F to 79°F on the shell side. The tube side pressure drop is assumed to be 5 psi.

PHX1 - Purchase Cost: $310,886

This is a carbon steel kettle heat exchanger used to lower the temperature of natural gas stream NG2 from 107°F to 70°F. The necessary heat duty is 30,900,953 BTU/hr. The surface area is calculated as 32,679 ft² using 64°F propane on the shell side. The tube side pressure drop is assumed to be 5 psi.

PHX2 - Purchase Cost: $355,046

This is a carbon steel kettle heat exchanger used to lower the temperature of natural gas stream NG3 from 70°F to 30°F. The necessary heat duty is 34,036,259 BTU/hr. The surface area is calculated as 37,376 ft² using 25°F propane on the shell side. The tube side pressure drop is assumed to be 5 psi.

PHX3 - Purchase Cost: $433,088

This is a carbon steel kettle heat exchanger used to lower the temperature of natural gas stream NG4 from 30°F to -30°F. The necessary heat duty is 53,926,388 BTU/hr. The surface area is calculated as 45,224 ft² using -35°F propane on the shell side. The tube side pressure drop is assumed to be 5 psi.

6.2.3 Turbines

To ensure reliability, each compression step in the process is run in parallel with two 50% compressors.

T1 - Purchase Cost: $359,055

This is a carbon steel turbine used to expand the mixed refrigerant stream from 600 psia to 49 psia, before entering the warm bundle. The isentropic efficiency is assumed to be 0.72. The flow rate through the turbine is 2,447,630 lb/hr. The power generated by the turbine is 2,764 hp.

T2 - Purchase Cost: $218,319

This is a carbon steel turbine used to expand the mixed refrigerant stream from 600 psia to 51 psia, before entering the cold bundle. The isentropic efficiency is assumed to be 0.72. The flow rate through the turbine is 1,568,650 lb/hr. The power generated by the turbine is 1,358 hp.

6.3: Unit Equipment Sheets

Table 6.3: Equipment summary sheet for C1

Compressor		
Identification	Item:	Single-Stage
	Item No:	C1
	No. Req'd:	2
Function:	Compress propane stream	
Operation:	Continuous	
Type:	Centrifugal	
Materials Handled	**Stream In:**	**Stream Out:**
	P26	P27
Flow Rate (lb/hr)	1,310,780	1,310,780
Temperature (°F)	-70	32
Pressure (psia)	4	18
Design Data:	Number of Stages	1
	Isentropic Efficiency	0.81
	Total work (hp)	9,120
	Material of Construction	Carbon Steel
Purchase Cost:	$ 2,883,652	
Bare Module Cost:	$ 7,023,192	
Utilities (USD/yr):	$ 4,416,634	

Table 6.4: Equipment summary sheet for C2

Compressor				
Identification	Item:			Single-Stage
	Item No:			C2
	No. Req'd:			2
Function:	Compress propane stream			
Operation:	Continuous			
Type:	Centrifugal			
Materials Handled	**Stream In:**			**Stream Out:**
	P13	P23	P27	P14
Flow Rate (lb/hr)	330,448	561,762	1,310,780	2,202,990
Temperature (°F)	5	-35	32	103
Pressure (psia)	18	18	18	61
Design Data:	Number of Stages			1
	Isentropic Efficiency			0.81
	Total work (hp)			14,299
	Material of Construction			Carbon Steel
Purchase Cost:	$		4,132,290	
Bare Module Cost:	$		10,064,275	
Utilities (USD/yr):	$		6,924,706	

Table 6.5: Equipment summary sheet for C3

Compressor				
Identification	Item:			Single-Stage
	Item No:			C3
	No. Req'd:			2
Function:	Compress propane stream			
Operation:	Continuous			
Type:	Centrifugal			
Materials Handled	**Stream In:**			**Stream Out:**
	P10	P14	P19	P15
Flow Rate (lb/hr)	141,621	2,202,990	802,518	3,147,130
Temperature (°F)	25	103	25	132
Pressure (psia)	61	61	61	115
Design Data:	Number of Stages			1
	Isentropic Efficiency			0.81
	Total work (hp)			11,225
	Material of Construction			Carbon Steel
Purchase Cost:	$		3,404,929	
Bare Module Cost:	$		8,292,772	
Utilities (USD/yr):	$		5,436,232	

Table 6.6: Equipment summary sheet for C4

Compressor			
Identification	Item:		Single-Stage
	Item No:		C4
	No. Req'd:		2
Function:	Compress propane stream		
Operation:	Continuous		
Type:	Centrifugal		
Materials Handled	**Stream In:**		**Stream Out:**
	P5	P15	P1
Flow Rate (lb/hr)	3,147,130	3,147,130	6,294,260
Temperature (°F)	64	132	147
Pressure (psia)	115	115	200
Design Data:	Number of Stages		1
	Isentropic Efficiency		0.81
	Total work (hp)		18,824
	Material of Construction		Carbon Steel
Purchase Cost:	$	5,149,030	
Bare Module Cost:	$	12,540,566	
Utilities (USD/yr):	$	9,116,322	

Table 6.7: Equipment summary sheet for C5

Compressor		
Identification	Item:	Single-Stage
	Item No:	C5
	No. Req'd:	2
Function:	Compress mixed refrigerant stream	
Operation:	Continuous	
Type:	Centrifugal	
Materials Handled	**Stream In:**	**Stream Out:**
	MR1	MR2
Flow Rate (lb/hr)	4,016,290	4,016,290
Temperature (°F)	-58	168
Pressure (psia)	49	350
Design Data:	Number of Stages	1
	Isentropic Efficiency	0.81
	Total work (hp)	67,774
	Material of Construction	Carbon Steel
Purchase Cost:	$ 14,348,426	
Bare Module Cost:	$ 34,945,878	
Utilities (USD/yr):	$ 32,822,239	

Table 6.8: Equipment summary sheet for C6

Compressor		
Identification	Item:	Single-Stage
	Item No:	C6
	No. Req'd:	2
Function:	Compress mixed refrigerant stream	
Operation:	Continuous	
Type:	Centrifugal	
Materials Handled	**Stream In:**	**Stream Out:**
	MR3	MR4
Flow Rate (lb/hr)	4,016,290	4,016,290
Temperature (°F)	150	229
Pressure (psia)	345	615
Design Data:	Number of Stages	1
	Isentropic Efficiency	0.81
	Total work (hp)	25,541
	Material of Construction	Carbon Steel
Purchase Cost:	$ 6,572,720	
Bare Module Cost:	$ 16,007,991	
Utilities (USD/yr):	$ 12,369,276	

Table 6.9: Equipment summary sheet for T1

Turbine		
Identification	Item:	Turbine
	Item No:	T1
	No. Req'd:	1
Function:	Expand liquid mixed refrigerant	
Operation:	Continuous	
Type:	N/A	
Materials Handled	**Stream In:**	**Stream Out:**
	MRA2	MRA3
Flow Rate (lb/hr)	2,447,630	2,447,630
Temperature (°F)	-170	-189
Pressure (psia)	600	49
Design Data:	Number of Stages	1
	Isentropic Efficiency	0.72
	Total work (hp)	-2,764
	Material of Construction	Carbon Steel
Purchase Cost:	$ 359,055	
Bare Module Cost:	$ 874,485	
Utilities (USD/yr):	N/A	

Table 6.10: Equipment summary sheet for T2

Turbine		
Identification	Item:	Turbine
	Item No:	T2
	No. Req'd:	1
Function:	Expand liquid mixed refrigerant	
Operation:	Continuous	
Type:	N/A	
Materials Handled	**Stream In:**	**Stream Out:**
	MRB3	MRB4
Flow Rate (lb/hr)	1,568,650	1,568,650
Temperature (°F)	-262	-268
Pressure (psia)	600	51
Design Data:	Number of Stages	1
	Isentropic Efficiency	0.72
	Total work (hp)	-1,358
	Material of Construction	Carbon Steel
Purchase Cost:	$ 218,319	
Bare Module Cost:	$ 531,720	
Utilities (USD/yr):	N/A	

Table 6.11: Equipment summary sheet for PHX1

Heat Exchanger		
Identification	Item: Item No: No. Req'd:	Heat Exchanger PHX1 1
Function:	Cool incoming natural gas from NG2	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	NG2	P3
Stream Out	NG3	P4
Flow Rate (lb/hr)	1,372,300	6,294,300
Temperature In (°F)	107	64
Temperature Out (°F)	70	64
Design Data:	Shell Pressure (psia)	115
	Tube OD (in)	1
	Length (ft)	20
	Surface Area (ft^2)	32,679
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	18.95
	Heat Duty (BTU/hr)	30,900,953
	U (BTU/hr ft^2 °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 310,886	
Bare Module Cost:	$ 1,117,529	
Utilities (USD/yr):	$ N/A	

Table 6.12: Equipment summary sheet for PHX2

Heat Exchanger		
Identification	Item:	Heat Exchanger
	Item No:	PHX2
	No. Req'd:	1
Function:	Cool incoming natural gas from NG3	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	NG3	P8
Stream Out	NG4	P9
Flow Rate (lb/hr)	1,372,300	472,070
Temperature In (°F)	70	25
Temperature Out (°F)	30	25
Design Data:	Shell Pressure (psia)	61
	Tube OD (in)	1
	Length (ft)	20
	Surface Area (ft²)	37,376
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	18.25
	Heat Duty (BTU/hr)	34,036,259
	U (BTU/hr ft² °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 355,046	
Bare Module Cost:	$ 1,274,963	
Utilities (USD/yr):	$ N/A	

Table 6.13: Equipment summary sheet for PHX3

Heat Exchanger		
Identification	Item:	Heat Exchanger
	Item No:	PHX3
	No. Req'd:	1
Function:	Cool incoming natural gas from NG3	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	NG4	P12
Stream Out	NG5	P13
Flow Rate (lb/hr)	1,372,300	330,450
Temperature In (°F)	30	-35
Temperature Out (°F)	-30	5
Design Data:	Shell Pressure (psia)	18
	Tube OD (in)	1
	Length (ft)	20
	Surface Area (ft²)	45,224
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	23.9
	Heat Duty (BTU/hr)	53,926,388
	U (BTU/hr ft² °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 433,088	
Bare Module Cost:	$ 1,555,209	
Utilities (USD/yr):	$ N/A	

Table 6.14: Equipment summary sheet for MHX1

Heat Exchanger		
Identification	Item:	Heat Exchanger
	Item No:	MHX1
	No. Req'd:	1
Function:	Cool incoming mixed refrigerant from MR5	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	MR5	P17
Stream Out	MR6	P18
Flow Rate (lb/hr)	4,016,300	2,675,100
Temperature In (°F)	107	25
Temperature Out (°F)	65	25
Design Data:	Shell Pressure (psia)	61
	Tube OD (in)	1
	Length (ft)	20
	Surface Area (ft^2)	31,456
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	58.54
	Heat Duty (BTU/hr)	91,885,170
	U (BTU/hr ft^2 °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 298,304	
Bare Module Cost:	$ 1,071,203	
Utilities (USD/yr):	$ N/A	

Table 6.15: Equipment summary sheet for MHX2

Heat Exchanger		
Identification	Item:	Heat Exchanger
	Item No:	MHX2
	No. Req'd:	1
Function:	Cool incoming mixed refrigerant from MR6	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	MR6	P21
Stream Out	MR7	P22
Flow Rate (lb/hr)	4,016,300	1,872,500
Temperature In (°F)	65	-35
Temperature Out (°F)	16	-35
Design Data:	Shell Pressure (psia)	18
	Tube OD (in)	1
	Length (ft)	20
	Surface Area (ft²)	74,056
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	68.89
	Heat Duty (BTU/hr)	254,565,704
	U (BTU/hr ft² °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 746,556	
Bare Module Cost:	$ 2,680,864	
Utilities (USD/yr):	$ N/A	

Table 6.16: Equipment summary sheet for MHX3

Heat Exchanger		
Identification	Item:	Heat Exchanger
	Item No:	MHX3
	No. Req'd:	1
Function:	Cool incoming mixed refrigerant from MR7	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	MR7	P25
Stream Out	MR8	P26
Flow Rate (lb/hr)	4,016,300	1,310,800
Temperature In (°F)	16	-89
Temperature Out (°F)	-27	-70
Design Data:	Shell Pressure (psia)	4
	Tube OD (in)	1
	Length (ft)	20
	Surface Area (ft²)	55,595
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	81.8
	Heat Duty (BTU/hr)	226,900,396
	U (BTU/hr ft² °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 541,084	
Bare Module Cost:	$ 1,943,020	
Utilities (USD/yr):	$ N/A	

Table 6.17: Equipment summary sheet for MHT1

Heat Exchanger		
Identification	Item: Cooler Item No: MHT1 No. Req'd: 1	
Function:	Cool incoming mixed refrigerant from MR2	
Operation:	Continuous	
Type:	Floating Head Heat Exchanger	
	Tube Side	**Shell Side**
Stream In	MR2	Cooling Water
Stream Out	MR3	Cooling Water
Flow Rate (lb/hr)	4,016,300	2,218,380
Temperature In (°F)	168	65
Temperature Out (°F)	150	79
Design Data:	Shell Pressure (psia)	22
	OD Tube (in)	1
	Length (ft)	20
	Surface Area (ft²)	2,956
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	86.89
	Heat Duty (BTU/hr)	35,756,160
	U (BTU/hr ft² °F)	140
	Construction Materials	Carbon Steel
Purchase Cost:	$ 34,829	
Bare Module Cost:	$ 125,071	
Utilities (USD/yr):	$ 0	

Table 6.18: Equipment summary sheet for MHT2

Heat Exchanger		
Identification	Item: Cooler Item No: MHT2 No. Req'd: 1	
Function:	Cool incoming mixed refrigerant from MR2	
Operation:	Continuous	
Type:	Floating Head Heat Exchanger	
	Tube Side	**Shell Side**
Stream In	MR4	Cooling Water
Stream Out	MR5	Cooling Water
Flow Rate (lb/hr)	4,016,300	16,176,300
Temperature In (°F)	229	65
Temperature Out (°F)	107	79
Design Data:	Shell Pressure (psia)	22
	OD Tube (in)	1
	Length (ft)	20
	Surface Area (ft^2)	22,992
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	84.78
	Heat Duty (BTU/hr)	260,722,140
	U (BTU/hr ft^2 °F)	140
	Construction Materials	Carbon Steel
Purchase Cost:	$ 163,255	
Bare Module Cost:	$ 586,244	
Utilities (USD/yr):	$ 0	

Table 6.19: Equipment summary sheet for PHT

Heat Exchanger		
Identification	Item: Cooler Item No: PHT No. Req'd: 1	
Function:	Cool incoming mixed refrigerant from P1	
Operation:	Continuous	
Type:	Floating Head Heat Exchanger	
	Tube Side	**Shell Side**
Stream In	P1	Cooling Water
Stream Out	P2	Cooling Water
Flow Rate (lb/hr)	6,294,260	61,385,100
Temperature In (°F)	147	65
Temperature Out (°F)	100	79
Design Data:	Shell Pressure (psia)	22
	OD Tube (in)	1
	Length (ft)	20
	Surface Area (ft²)	228,949
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	32.4
	Heat Duty (BTU/hr)	989,561,416
	U (BTU/hr ft² °F)	140
	Construction Materials	Carbon Steel
Purchase Cost:	$ 2,267,543	
Bare Module Cost:	$ 8,142,693	
Utilities (USD/yr):	$ 0	

Table 6.20: Equipment summary sheet for CHX1

Heat Exchanger		
Identification	Item:	Heat Exchanger
	Item No:	CHX1
	No. Req'd:	1
Function:	Liquefy natural gas from NG4	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	NG4, MRA1, MRB1	MRAB
Stream Out	NG5, MRA2, MRB2	MR1
Flow Rate (lb/hr)	5,288,530	4,016,290
Temperature In (°F)	-29	-193
Temperature Out (°F)	-170	-58
Design Data:	Shell Pressure (psia)	49
	OD Tube (in)	1
	Length (ft)	20
	Surface Area (ft^2)	1,291,990
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	12.73
	Heat Duty (BTU/hr)	820,420,000
	U (BTU/hr ft^2 °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 124,723,097	
Bare Module Cost:	$ 447,877,647	
Utilities (USD/yr):	$ N/A	

Table 6.21: Equipment summary sheet for CHX2

Heat Exchanger		
Identification	Item:	Heat Exchanger
	Item No:	CHX2
	No. Req'd:	1
Function:	Cool natural gas from NG5	
Operation:	Continuous	
Type:	Shell and Tube Kettle	
	Tube Side	**Shell Side**
Stream In	NG5, MRB2	MRB4
Stream Out	NG6, MRB3	MRB5
Flow Rate (lb/hr)	2,940,900	1,568,650
Temperature In (°F)	-170	-267.58
Temperature Out (°F)	-262	-198.7
Design Data:	Shell Pressure (psia)	49
	OD Tube (in)	1
	Length (ft)	20
	Surface Area (ft²)	311,183
	Tube Pitch (in)	1.25
	Log Mean ΔT (°F)	13.9
	Heat Duty (BTU/hr)	215,900,000
	U (BTU/hr ft² °F)	50
	Construction Materials	Carbon Steel
Purchase Cost:	$ 14,021,908	
Bare Module Cost:	$ 50,352,335	
Utilities (USD/yr):	$ N/A	

Section 7

Energy Balance & Utility Requirements

7.1 Work Integration Strategy

7.1.1 Cooling Water

Cooling water is one of the main utilities used in this natural gas liquefaction process. Each of the coolers in this design uses cooling water to remove heat. While air coolants can be used on some occasions, cooling water is the best option to meet the desired temperatures required in this process. A common heuristic states that cooling water typically enters a utility exchanger at 90°F and exits at no higher than 120°F. Cooling water is capable of cooling process streams down to approximately 100°F. If a process stream must be cooled to below 100°F, refrigerants would have to be purchased, incurring significant costs. In such cases, a commonly-used refrigerant is propane, which has a temperature range of -40°F to 20°F.

The Cove Point facility is conveniently located on the coast of the Atlantic Ocean, a source of readily accessible water. However, environmental regulations to minimize thermal pollution mandate that seawater cannot be discharged more than 14°F above the temperature of the water source it was originally removed from. The heat capacity of seawater is approximately 0.953 Btu / lb-°F. Seawater is assumed to be available at a temperature of 65°F, and therefore has a maximum outlet temperature of 79°F. These estimates and the cooling duties of the utility heat exchangers were used to estimate the required amount of cooling water needed by this process. These cooling water calculations can be found in Appendix C on page 273.

Cooling water will be supplied to this liquefaction process using existing equipment from Cove Point's current gasification facility. Compared to constructing an entirely new liquefaction facility, this retrofit project allows us to use a variety of existing pumps to supply cooling water. A large number of new pumps will not need to be purchased for this project. Cove Point's existing equipment contains corrosion-resistant materials and can handle the abrasive seawater.

7.1.2 Electricity

In order to help meet the power requirements of this process, two turbines are installed in place of valves near the main cryogenic heat exchanger. These turbines (T1 and T2) produce useful energy that can partially offset the electricity requirement of a propane compressor (C1).

Table 7.1 Electricity Savings

T1 and T2 Electricity Savings	
C1 Electricity Requirement	6,801 kW
T1 Electricity Requirement	-2,061 kW
T2 Electricity Requirement	-1,012 kW
Net Electricity Required	3,727 kW
Electricity Saved	3,073 kW
Savings	$1,995,895 /yr
Cost of T1	$359,055
Cost of T2	$218,319
Payback Period	0.29 yrs

By generating electricity from the mixed refrigerant expansions, $1,995,895 of savings in electrical utilities is realized. The investments in the $359,055 TI and $218,319 T2 turbines have a combined payback period of 0.29 years.

Table 7.2 Equipment electricity requirements

Electricity	**kW**	**Cost (USD/hr)**	**Cost (USD/yr)**
C1	3,727.43	$305.65	$2,420,739.40
C2	10,662.58	$874.33	$6,924,706.22
C3	8,370.64	$686.39	$5,436,231.52
C4	14,037.20	$1,151.05	$9,116,322.38
C5	50,539.29	$4,144.22	$32,822,238.80
C6	19,046.06	$1,561.78	$12,369,276.18
Pumps	640.26	$52.50	$415,812.85
Total	107023.5	$8,775.93	$69,505,327.35

Section 8

Other Considerations

8.1 Plant Location & Start-Up

The Cove Point import facility is already strategically located in Maryland, with access to an abundant supply of natural gas from the Marcellus Shale as well as access to a port for LNG export after the import facility is appropriately retrofitted. Additionally, this plant location provides convenient access to cooling water for this liquefaction process.

The plant start-up process is similar to that of many liquefaction plants, in which the start-up will begin by first removing moisture from the entire system. This drying process can be accomplished using chemicals such as dry nitrogen. For a low temperature cryogenic process such as this, each equipment unit must slowly be cooled before any contact takes place between the cold liquids. The liquefaction process also contains a large number of heat exchangers that are used to precool the mixed refrigerant and natural gas before they enter the main cryogenic heat exchanger. These complex equipment units can be challenging to start running, and great attention must be placed in this critical initiation step. Despite these challenges, once the plant progresses past the initial startup phase, daily operations are expected to run more smoothly.

8.2 Transportation & Storage

Please see above sections describing existing storage facilities located at Cove Point and the process by which LNG is transported.

8.3 Process Controllability

In this liquefaction process, one aspect that must be tightly controlled is the heat gain from ambient surroundings. With some equipment units operating at -260°F, any heat absorbed from the environment will negatively impact the efficiency of this liquefaction process. One method to ensure minimal heat gain from surroundings is through the use of a cold box.[15] A cold box is a carbon steel structure that encases the MCHE. Insulation fills the space between the cold box and the heat exchanger, protecting the heat exchanger from ambient heat.

Another aspect of this liquefaction process that must be controlled are the compressors that handle high flow rates. High flow rate compressors in LNG processes can be easily damaged by compressor surge, which consists of high energy and high speed flow reversals within a compressor. One method to avoid compressor surge is by combining feedforward controls and anti-surge controllers, thus ensuring continuous operation.[16] Another more common control method is the use of 50% parallel compressor trains. The total compression burden is shared by two compressors each handling 50% of the total flow. Parallel trains also ensure reliability in that if one compressor must be taken down and repaired, the entire liquefaction process can continue running at half capacity instead of being taken offline completely.

[15] Chart LNG. "LNG Equipment Cold Boxes." 2012.Web.<http://www.chartlng.com/Equipment/Cold_Boxes.aspx>.
[16] Wu, Jihong, et al. "A Realistic Dynamic Modeling Approach to Support LNG Plant Compressor Operations." *LNG Journal* (2007)Web.

8.4 Maintenance

All equipment must be properly maintained to minimize unforeseen shutdowns that could cost millions of dollars in idle time. This process design assumes the liquefaction plant is fully operational for 330 days a year, with about 1 month for regular maintenance. Routine maintenance includes the diligent inspection of all equipment units including heat exchangers, turbines, compressors, pumps, and pipes. Heat exchangers must be inspected for corrosion that could lead to poor heat transfer performance. Turbines must be monitored regularly for damage from high vaporization of mixed refrigerant. Compressors and pumps must be checked for physical damage from handling such high flow rates. As mentioned above, parallel compressor trains reduce the burden on compressors and allow half the compressors to be taken offline if necessary.

8.5 Emergency Procedures

In the event of an emergency, this liquefaction process is equipped with process control valves that can be closed to shut off flow of natural gas to the precoolers and main cryogenic heat exchanger. Anti-surge valves for the mixed refrigerant compressors will open up to avoid compressor surge. Additionally, power can be turned off for the compressors and pumps to further stop the process. Fire extinguishers and safety procedures should be implemented according to proper building and industrial codes. In the case of uncontrollable emergencies, plant personnel should evacuate accordingly.

8.6 Process Safety and Health Concerns

Strict standards must be followed with the handling of liquefied natural gas and all the components in this process. Natural gas is highly flammable in its gaseous state, and can also vaporize quickly in its liquid state, potentially creating extremely dangerous explosion hazards. As a result, regular inspections and maintenance on all pieces of equipment must be performed to reduce these risks. Maintenance ensures that equipment units do not corrode, which could lead to damaged equipment and hazardous leaks. All units in this process are operated at pressures much greater than atmospheric pressure. This maintenance of high pressures ensures that for any equipment leak, natural gas will exit the unit into the surroundings. Without this high pressure, leaks would cause air to seep into the equipment units, potentially igniting the entire natural gas supply in the process.

With respect to process safety and health concerns, appropriate material safety data sheets are located in the appendix of this report.

8.7 Environmental Considerations

Environmental concerns are not to be taken lightly. Driven only by environmental considerations, extensive lobbying is underway in Maryland to potentially block any sort of retrofit project to the Cove Point facility. For this project, the most important environmental impacts are those regarding waste minimization, protection of marine life and other wildlife, as well as minimization of air pollution and the plant’s overall carbon footprint. There are several ways to manage each of these concerns.

Waste minimization can be achieved by reducing the solid waste produced by a process. Fortunately, this particular process produces virtually no solid waste that would need to comply with the Federal Hazardous and Solid Waste Amendments (HSWA) outlined in the Resource

Conservation and Recovery Act (RCRA). Protection of marine life and wildlife can be achieved by preventing spills or leaks of any kind. This prevention can be accomplished by rigorously complying with all required maintenance and taking extra precautions in designing safe equipment.

Air pollution can be minimized using several different methods. First, a common industry practice of smokeless flaring burns off any excessive gas that may be in the process at a given point in time. While flaring is not completely harmless to the environment, it is a necessary safety precaution. Moreover, certain technologies and control systems can be used to burn off vapors that originate from volatile organic compounds (VOCs). If not burned off appropriately, these vapors will contribute to smog formation in the environment. While the Environmental Protection Agency (EPA) currently does not fully regulate CO2 emissions, the EPA strongly regulates NOx and COx emissions. The EPA has primary standards for NOx emissions set at 100 parts per billion (ppb), which is easily met by this process design. The primary standards for CO production is 35 parts per million (ppm), which is also met by this process design given the assumed pre-treatment facilities.

Section 9

Cost Summaries

The costs for this process can be divided into two distinct categories: costs associated with a total capital investment required to develop the physical infrastructure and production costs that are associated with the continuous operation of the process facility. Both of these costs are scrutinized and estimated below to determine the total expenditures needed to develop and run this liquefaction process.

9.1 Total Capital Investment

Table 9.1 Breakdown of total capital investment

Total bare module costs for equipment	$	607,007,659
Total bare module costs for spares	$	-
Total bare module costs for storage and surge tanks	$	10,000,000
Total cost for initial catalyst charges	$	-
Total bare module costs for computers, software, alarms	$	6,070,077
Total bare module investment, TBM	$	623,077,735
Cost of site preparation	$	62,307,774
Cost of service facilities	$	31,153,887
Allocated costs for utility plants and related facilities	$	30,350,383
Total of direct permanent investment, DPI	$	746,889,779
Cost of contingencies and contractors fee	$	134,440,160
Total depreciable capital, TDC	$	881,329,939
Cost of land	$	-
Cost of royalties	$	-
Cost of plant startup	$	17,626,599
Total permanent investment, TPI	$	988,852,191
Working capital	$	325,952,283
Total capital investment, TC	**$**	**1,314,804,475**

9.1.1 Total Bare Module Investment (TBM)

The TBM estimates all the costs associated with the acquisition and installation of key components of the process. The total bare module costs for equipment was determined in Section 6 by costing the main unit operations of the process. Additionally, the total bare module cost for storage tanks and other auxiliary equipment was estimated at $10 million. While the storage tanks already exist at the site location, retrofitting these pieces of equipment will require this upfront cost. Finally, the cost of the software, controllers, and alarms was assumed to be 1% of the cost of the equipment piece, totaling approximately $6 million. Together, the total bare module cost is $623,077,735, and comes almost entirely from the purchased pieces of equipment.

9.1.2 Total of Direct Permanent Investment (DPI)

The DPI includes the TBM in addition to costs associated with land and facilities. Because this process is retrofitting an existing plant, the site and the utility plant and related facilities already exist. However, numerous alterations to the landscape must be made to the facility, including the construction of a 60 foot wall around the plant designed to minimize sound pollution. It is estimated that these site preparation costs will be 10% of the TBM. Additionally, the conversion from import to export will result in more employees and personnel on site. It is estimated that the cost to build and upgrade all supporting service facilities such as cafeterias and maintenance shops to support this change will be 5% of the TBM. In total, the DPI is estimated to be $746,889,779.

Total Depreciable Capital (TDC)

The TDC includes contingency costs for unanticipated events and contractors' fees. The fees are estimated as 3% of the DPI. The contingency costs associated with this process are estimated as 15% of the DPI because LNG liquefaction is a well-known process and it is assumed a catastrophic accident is less likely. The TDC is $881,329,939.

Total Permanent Investment (TPI)

The TPI includes the TDC as well as non-depreciable considerations such as land, royalties, and startup costs. The land for this facility has been previously purchased and there are no known royalties. The cost for plant startup can be estimated anywhere between 2-30%. Because LNG liquefaction and export facilities are increasingly common and companies such as Air Products and Linde have extensive experience designing them, it is assumed that the startup costs will be relatively small compared to lesser known processes requiring a high degree of optimization and integration. Thus the startup cost is assumed to be 2% of the TDC, resulting in a TPI of $988,852,191.

Total Capital Investment (TC)

The total capital investment is the sum of all above costs as well as working capital. The working capital is calculated as cash reserves + inventory +accounts receivable – accounts payable. We assume one month of cash reserves, or 8.33% of the annual manufacture cost, one week of inventory, or 1.92% of annual LNG sales, and 30 days of accounts receivable and payable as 8.33% of annual sales and natural gas purchase prices, respectively. The working capital is determined to be $325,952,283. The total capital investment for the project is $1.31

billion as detailed in Table 9.1. Roughly 25% of the total capital investment is from working capital and 46% from the equipment base module costs.

Table 9.2: Breaking down of working capital costs

8.33% Cost of Manufacturing	$	20,323,988
1.92% Annual Sales	$	77,552,640
8.33% Annual Sales	$	335,253,600
8.33% Annual NG	$	107,177,945
Working Capital	**$**	**325,952,283**

9.2 Total Annual Costs

The annual production costs for the process are composed of a cost of manufacture and general expenses. The cost of manufacture includes the price of natural gas feed, utilities, labor, operating overhead, and fixed costs including taxes and depreciation.

9.2.1 Utilities

As previously mentioned, cooling water for this process is taken from the sea and is assumed free. However, the power needed to operate the pumps for the cooling water as well as the compressors in the process require a utility of $ 69,505,327.35 shown in Section 7.

9.2.2 General Expenses

The general expenses are funded by the process profits for the central operations of the company, Dominion Resources. It is estimated that the expense to sell the LNG including advertising, research, administrative cost, and management incentive compensations are 3%, 4.8%, 2%, and 1.25% of the total sales. With estimated sales of just over $4 billion, the general expenses are estimated at $ 446,331,600.00

Table 9.3 Breakdown of annual production costs

Utilities		
	Steam Water	$ -
	Electricity	$ 69,505,327
Operations		
	Direct Wages and Benefits	$ 3,640,000
	Direct Salaries and Benefits	$ 546,000
	Operating supplies and services	$ 218,400
	Technical assistance	$ 600,000
	Control laboratory	$ 650,000
Maintenance		
	Wages & Benefits	$ 30,846,548
	Salaries and benefits	$ 7,711,637
	Materials and services	$ 30,846,548
	Maintenance overhead	$ 1,542,327
Operating Overhead		
	General plant overhead	$ 3,034,837
	Mechanical dept.	$ 1,025,860
	Employee relations dept.	$ 2,521,907
	Business services	$ 3,163,070
Property taxes and insurance		$ 17,626,599
Depreciation		
	Direct Plant	$ 70,506,395
COST OF MANUFACTURE		$ 243,985,455
General Expenses		
	Transfer Expense	$ 121,176,000
	Direct Research	$ 193,881,600
	Allocated Research	$ -
	Administrative expense	$ 80,784,000
	Management incentive compensation	$ 50,490,000
TOTAL GENERAL EXPENSES		$ 446,331,600
TOTAL ANNUAL PRODUCTION COST		**$ 690,317,055**

Section 10

Economic Analysis

10.1 Economic Analysis

The economic analysis of this process was conducted using a discounted cash flow (DCF) approach. For this method it is assumed that it will take one year to design this plant, four years to construct and the plant will produce for approximately 20 years – therefore bringing the total timeline for the project to 25 years.[17] Four years was selected for the construction time based on the construction times for similarly built plants. The site factor for the plant is 1.10 as it is being built in the U.S. Northeast. This timeline will set how far cash flows need to be projected out in the DCF analysis. The plant is assumed to operate 94% of the time during the year, as this is standard for LNG facilities of this size. Capital equipment will be depreciated using the MACRS depreciation schedule on a 15 year time frame. A conservative 37% income tax rate is used, ignoring any potential tax credits, a 20% discount rate and a 2.5% general inflation rate. The discount rate should reflect the perceived risk of the project. A 20% discount rate is on the conservative side for this project[18]. Using production forecasts for the plant along with price forecasts a DCF can be modeled fairly easily. The economics of the project are most sensitive to the commodity price of natural gas both in its gaseous state and liquefied state. As is commonly done when costing projects of this size in the energy industry a flat price deck is used since it is far too difficult to predict how commodity prices will change over a 25 year time period. A conservative price of roughly $520 per ton of LNG is used, taking into account the transportation costs that would be incurred by shipping LNG from the United States to overseas markets. An input cost of $5.00 per mmbtu of natural gas is assumed.

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[17] Macquarie Capital Markets Canada Ltd. *Canadian LNG: The Race to the Coast*. Macquarie Private Wealth Inc., 2012. Web.
[18] Oil and Gas Journal. "Processing."Web. <http://www.ogj.com/articles/print/vol-110/issue-12/processing.html>.

Based upon these assumptions the DCF analysis resulted in a NPV of $219MM and an IRR of 23.5%. The cash flows that led to this are summarized in the table below.

The two main drivers of profitability for this plant are 1) the fact that it is a retrofit project and 2) the large spread in natural gas prices that exists between the U.S. and international markets. If the plant had to be built completely from the ground up, the capital cost would have been significantly higher thus driving down the NPV and IRR respectively. It is also important to note that when a plant such as this one is commissioned there is always a Power Purchasing Agreement in place between a willing buyer for the product and the party undertaking the risk of building the plant in the first place. Usually these PPAs are locked in for 20 to 25 years, roughly the time frame for which the plant will produce. While the details of the PPA can be quite intricate in terms of tracking multiple commodity market indices in a variety of countries and having various rules that govern what the specific price will be under a variety of events, they ultimately have the effect of guaranteeing some base price for the party that undertakes the risk of making a large long term investment.

10.1.1 Retrofitting Versus Building a New Facility

The high IRR can be partially attributed to the fact that this is a retrofit project. If this were not a retrofit project then one would expect both the fixed cost in the form of total permanent investment to rise as well as the time to build the plant to increase. The time required for permitting, procuring the land and preparing the land for building the plant would easily add on another two years to the timeline before any production could come online. The fixed costs would rise from paying for the land, building additional facilities including pipelines, storage tanks, docks for tanker loading, utility facilities and treatment facilities. Already having a built dynamic discounted cash flow model makes it easy to determine how these two changes would impact the project economics.

Extending the construction time by two years by itself decreases the IRR, holding all else constant, to 18.5%. This is a decrease of 5% in the internal rate of return. With the project timeline extended by two years a sensitivity data table can be created with varying total permanent investment on one axis and product price on the other. If total permanent investment increases by 50% (which is a reasonable assumption) as a result of not retrofitting an existing facility, the internal rate of return drops 9.1% to 9.4%. Therefore, it can be argued that retrofitting the Cove Point facility has the potential to add another 14.4% to the IRR of the project.

The economics of this project under the base case scenario are very attractive, which is why there a huge push in the United States currently to build a large number of export facilities. It is worth noting that not all of these projects are retrofit plants though, which must mean that the economics must be favorable even for a completely new plant design. The economics run here seem to corroborate this by showing that even by extending the construction time and allowing for a 50% increase in total permanent investment, it is still possible to achieve approximately a 10% IRR. It is unlikely a plant would be built if the IRR was much below 10% under base case assumptions as this return does not justify the risk undertaken.

10.1.2 The Impact on Economics of Movements in the Price Spread

There are two main forces driving the economics in terms of pricing. The price spread is the difference between what liquefied natural gas is sold at and what the raw natural gas is bought at. The first driver is the raw material cost of the natural gas that will be purchased as a feed for the plant. As discussed earlier in the report natural gas prices have declined dramatically because of a large increase in supply in the United States. However, it is not the short term natural gas price that matters but rather what the long term price will be over the next 25 years. Futures contracts on physical delivery of natural gas to Henry Hub currently range from $4 to $5.50 per mmbtu out through April 2024. These numbers indicate that the market is not expecting any significant increase in natural gas prices in the near future, most likely as a result of extremely large natural gas supplies in the United States. It would be technically possible to lock in these prices using commodity derivatives to eliminate any risk in a run up in these input prices. However, that is usually not necessary as it is also possible to secure a power purchasing agreement on the purchasing of natural gas which can lock in prices for the duration of the project. The second force at play here is the international market price for LNG. It is assumed that this plant will sell LNG exclusively to Japan by signing a long term PPA. Prices for LNG in Japan have been at all time highs over the past two years. In terms of pricing, LNG prices have been as high as $900 per ton of LNG but historically have averaged around $350 per ton. A price of $650 per ton of LNG (roughly $13.5 per mmbtu) was selected for use in the base case economics. Then 20% of that price needs to be removed for shipping costs including insurance and freight (commonly referred to as CIF). Accounting for all factors then provides for a 'net' price of $520 per ton of LNG that one would receive for selling this product to Japan.

Under the base case assumptions the breakeven 'net' LNG price is $400 or $500 gross per ton of LNG (equivalent to $10.2 per mmbtu). This translates into a breakeven spread of $5.00 per mmbtu between the cost of natural gas and price of the LNG product. This breakeven spread is confirmed by independent studies conducted by Ernst and Young[19]. The interesting

[19] EYGM Limited. *Global LNG: Will New Demand and New Supply Mean New Pricing?* ., 2013. Web.

thing to note is that prior to 2008 the spread between natural gas prices in the United States and Japan was not nearly larger enough to surpass this breakeven spread. Therefore it fairly clear to see that the increase in the spread is the primary catalyst behind building any sort of LNG export facility being built currently. The general impact of the product price on the IRR of the project can be seen in the sensitivity tables below.

10.2 Economic Sensitivities

Sensitivities can be run on a variety of factors impacting the economics including product price, variable costs, fixed costs, total permanent investment, inflation and discount rate. These sensitivities are shown in the tables presented below.

Table 10.1: Cash Flow Summary @ Product Unit Price of $520 per ton

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 20%
2013	0%		-	-	-	-	-	-	-	-	-	-	-
2014	0%		-	(1,001,021,800)	-	-	-	-	-	-	-	(1,001,021,800)	(834,184,800)
2015	0%		-	-	-	-	-	-	-	-	-	-	(834,184,800)
2016	0%		-	-	-	-	-	-	-	-	-	-	(834,184,800)
2017	0%			-	(82,058,800)	-	-	-	-	-	-	(82,058,800)	(873,757,900)
2018	45%	$520.00	1,312,740,000	-	(41,029,400)	(726,242,900)	(113,316,300)	(41,364,500)	431,816,300	(159,772,000)	272,044,300	272,379,400	(764,294,700)
2019	68%	$520.00	1,969,110,000	-	(41,029,400)	(1,116,598,400)	(116,149,200)	(78,592,600)	657,769,800	(243,374,800)	414,395,000	451,958,200	(612,934,900)
2020	90%	$520.00	2,625,480,000	-	-	(1,526,017,800)	(119,052,900)	(70,733,400)	909,675,900	(336,580,100)	573,095,800	643,829,200	(433,254,000)
2021	90%	$520.00	2,625,480,000	-	-	(1,564,168,300)	(122,029,300)	(63,701,400)	875,581,100	(323,965,000)	551,616,100	615,317,500	(290,150,800)
2022	90%	$520.00	2,625,480,000	-	-	(1,603,272,500)	(125,080,000)	(57,331,200)	839,796,300	(310,724,600)	529,071,700	586,402,900	(176,502,000)
2023	90%	$520.00	2,625,480,000	-	-	(1,643,354,300)	(128,207,000)	(51,540,200)	802,378,500	(296,880,000)	505,498,500	557,038,700	(86,537,100)
2024	90%	$520.00	2,625,480,000	-	-	(1,684,438,200)	(131,412,200)	(48,810,200)	760,819,500	(281,503,200)	479,316,300	528,126,500	(15,457,600)
2025	90%	$520.00	2,625,480,000	-	-	(1,726,549,100)	(134,697,500)	(48,810,200)	715,423,300	(264,706,600)	450,716,700	499,526,800	40,567,600
2026	90%	$520.00	2,625,480,000	-	-	(1,769,712,800)	(138,064,900)	(48,892,900)	668,809,400	(247,459,500)	421,349,900	470,242,800	84,518,300
2027	90%	$520.00	2,625,480,000	-	-	(1,813,955,700)	(141,516,500)	(48,810,200)	621,197,700	(229,843,100)	391,354,500	440,164,700	118,801,200
2028	90%	$520.00	2,625,480,000	-	-	(1,859,304,500)	(145,054,400)	(48,892,900)	572,228,100	(211,724,400)	360,503,700	409,396,600	145,373,300
2029	90%	$520.00	2,625,480,000	-	-	(1,905,787,200)	(148,680,800)	(48,810,200)	522,201,900	(193,214,700)	328,987,200	377,797,300	165,807,600
2030	90%	$520.00	2,625,480,000	-	-	(1,953,431,800)	(152,397,800)	(48,892,900)	470,757,500	(174,180,300)	296,577,200	345,470,100	181,379,000
2031	90%	$520.00	2,625,480,000	-	-	(2,002,267,600)	(156,207,800)	(48,810,200)	418,194,500	(154,731,900)	263,462,500	312,272,700	193,108,300
2032	90%	$520.00	2,625,480,000	-	-	(2,052,324,300)	(160,113,000)	(48,892,900)	364,149,800	(134,735,400)	229,414,400	278,307,300	201,819,600
2033	90%	$520.00	2,625,480,000	-	-	(2,103,632,400)	(164,115,800)	(24,405,100)	333,326,700	(123,330,900)	209,995,800	234,400,900	207,933,700
2034	90%	$520.00	2,625,480,000	-	-	(2,156,223,200)	(168,218,700)	-	301,038,100	(111,384,100)	189,654,000	189,654,000	212,056,200
2035	90%	$520.00	2,625,480,000	-	-	(2,210,128,800)	(172,424,100)	-	242,927,000	(89,883,000)	153,044,000	153,044,000	214,828,400
2036	90%	$520.00	2,625,480,000	-	-	(2,265,382,000)	(176,734,700)	-	183,363,200	(67,844,400)	115,518,800	115,518,800	216,572,100
2037	90%	$520.00	2,625,480,000	-	164,117,600	(2,322,016,600)	(181,153,100)	-	122,310,300	(45,254,800)	77,055,500	241,173,000	219,605,900

Table 10.2: Internal Rate of Return Sensitivities Under Base Case Model Assumptions

	Variable Costs										
Product Price	$806,936,522	$968,323,827	$1,129,711,131	$1,291,098,436	$1,452,485,740	***$1,613,873,044***	$1,775,260,349	$1,936,647,653	$2,098,034,958	$2,259,422,262	$2,420,809,567
$260	12.08%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$312	19.41%	15.05%	7.71%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$364	24.40%	21.35%	17.56%	12.11%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$416	28.36%	25.92%	23.11%	19.74%	15.28%	6.73%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$468	31.71%	29.64%	27.35%	24.75%	21.69%	17.86%	12.14%	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$520	34.64%	32.82%	30.86%	28.69%	26.26%	23.47%	20.08%	15.52%	Negative IRR	Negative IRR	Negative IRR
$572	37.26%	35.63%	33.90%	32.02%	29.96%	27.69%	25.10%	22.05%	18.18%	12.18%	Negative IRR
$624	39.64%	38.16%	36.60%	34.92%	33.13%	31.17%	29.02%	26.61%	23.82%	20.43%	15.79%
$676	41.83%	40.47%	39.04%	37.52%	35.91%	34.19%	32.32%	30.29%	28.03%	25.45%	22.41%
$728	43.86%	42.60%	41.27%	39.89%	38.42%	36.87%	35.21%	33.43%	31.49%	29.36%	26.96%
$780	45.75%	44.57%	43.34%	42.06%	40.71%	39.29%	37.79%	36.19%	34.48%	32.63%	30.61%

	Fixed Costs										
Product Price	$56,658,145	$67,989,774	$79,321,403	$90,653,033	$101,984,662	***$113,316,291***	$124,647,920	$135,979,549	$147,311,178	$158,642,807	$169,974,436
$260	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$312	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$364	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$416	11.50%	10.78%	9.98%	9.08%	8.03%	6.73%	4.86%	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$468	19.67%	19.32%	18.97%	18.61%	18.24%	17.86%	17.47%	17.07%	16.65%	16.22%	15.78%
$520	24.77%	24.52%	24.26%	24.00%	23.73%	23.47%	23.19%	22.92%	22.64%	22.35%	22.06%
$572	28.76%	28.55%	28.33%	28.12%	27.90%	27.69%	27.47%	27.24%	27.02%	26.79%	26.56%
$624	32.10%	31.91%	31.73%	31.55%	31.36%	31.17%	30.98%	30.79%	30.60%	30.41%	30.21%
$676	35.01%	34.85%	34.68%	34.52%	34.35%	34.19%	34.02%	33.85%	33.68%	33.51%	33.34%
$728	37.61%	37.47%	37.32%	37.17%	37.02%	36.87%	36.71%	36.56%	36.41%	36.26%	36.10%
$780	39.98%	39.84%	39.70%	39.57%	39.43%	39.29%	39.15%	39.01%	38.87%	38.73%	38.59%

Product Price	Total Permanent Investment										
	$500,510,897	$600,613,076	$700,715,255	$800,817,435	$900,919,614	***$1,001,021,793***	$1,101,123,972	$1,201,226,152	$1,301,328,331	$1,401,430,510	$1,501,532,690
$260	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$312	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$364	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$416	34.10%	26.80%	20.92%	15.92%	11.37%	6.73%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$468	43.83%	36.14%	30.15%	25.31%	21.29%	17.86%	14.88%	12.24%	9.86%	7.68%	5.66%
$520	50.86%	42.67%	36.32%	31.22%	27.01%	23.47%	20.42%	17.77%	15.44%	13.35%	11.47%
$572	56.55%	47.90%	41.20%	35.83%	31.40%	27.69%	24.51%	21.75%	19.33%	17.18%	15.25%
$624	61.38%	52.33%	45.31%	39.69%	35.06%	31.17%	27.85%	24.98%	22.45%	20.22%	18.23%
$676	65.61%	56.20%	48.90%	43.05%	38.23%	34.19%	30.73%	27.74%	25.12%	22.80%	20.74%
$728	69.40%	59.66%	52.11%	46.05%	41.06%	36.87%	33.29%	30.19%	27.47%	25.07%	22.93%
$780	72.83%	62.80%	55.02%	48.77%	43.62%	39.29%	35.59%	32.39%	29.59%	27.11%	24.90%

Product Price	Inflation										
	1.25%	1.50%	1.75%	2.00%	2.25%	***2.50%***	2.75%	3.00%	3.25%	3.50%	3.75%
$260	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$312	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$364	-14.20%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$416	14.31%	13.44%	12.43%	11.17%	9.49%	6.73%	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
$468	20.58%	20.12%	19.63%	19.10%	18.51%	17.86%	17.12%	16.26%	15.24%	13.95%	12.10%
$520	25.18%	24.88%	24.55%	24.21%	23.85%	23.47%	23.05%	22.61%	22.13%	21.61%	21.03%
$572	28.94%	28.71%	28.47%	28.22%	27.96%	27.69%	27.40%	27.10%	26.78%	26.45%	26.09%
$624	32.16%	31.97%	31.78%	31.59%	31.38%	31.17%	30.95%	30.73%	30.49%	30.24%	29.98%
$676	35.00%	34.85%	34.69%	34.53%	34.36%	34.19%	34.01%	33.83%	33.64%	33.44%	33.24%
$728	37.55%	37.42%	37.29%	37.15%	37.01%	36.87%	36.72%	36.57%	36.41%	36.25%	36.08%
$780	39.89%	39.77%	39.65%	39.54%	39.41%	39.29%	39.16%	39.03%	38.90%	38.76%	38.62%

Table 10.3: Internal Rate of Return Sensitivities Under Six-Year Construction Period

		Total Permanent Investment										
		$500,510,897	$600,613,076	$700,715,255	$800,817,435	$900,919,614	***$1,001,021,793***	$1,101,123,972	$1,201,226,152	$1,301,328,331	$1,401,430,510	$1,501,532,690
Product Price	$260	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$312	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$364	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$416	25.72%	20.48%	16.17%	12.44%	9.06%	5.80%	-7.21%	Negative IRR	Negative IRR	Negative IRR	Negative IRR
	$468	32.70%	27.42%	23.21%	19.72%	16.77%	14.20%	11.94%	9.92%	8.07%	6.38%	4.79%
	$520	37.49%	32.01%	27.66%	24.09%	21.08%	18.50%	16.24%	14.25%	12.46%	10.85%	9.37%
	$572	41.24%	35.57%	31.07%	27.38%	24.29%	21.63%	19.33%	17.29%	15.48%	13.85%	12.37%
	$624	44.36%	38.51%	33.88%	30.08%	26.89%	24.16%	21.80%	19.71%	17.86%	16.19%	14.68%
	$676	47.06%	41.05%	36.28%	32.38%	29.11%	26.31%	23.88%	21.74%	19.84%	18.14%	16.60%
	$728	49.43%	43.28%	38.40%	34.41%	31.05%	28.19%	25.70%	23.51%	21.57%	19.83%	18.25%
	$780	51.57%	45.29%	40.30%	36.22%	32.79%	29.86%	27.32%	25.09%	23.10%	21.32%	19.72%

Section 11

Conclusions & Recommendations

11.1 Conclusions

There are a few key recommendations to be made for the general design of a liquefied natural gas plant. The first is that given the enormous size of the plant there are naturally going to be very large cooling requirements for the natural gas. The choice of refrigerant to cool the natural gas and the choice of fluid to cool the refrigerant is key. For example, having the LNG plant located on the water is vital to ensuring viable economics. As discussed earlier in the report an enormous amount of cooling water is needed for the plant and having to purchase a vast majority of this water would increase the variable costs to a level that could easily make the project unprofitable. In a similar vein, selecting a mixed refrigerant that matches the heating and cooling curves in the main cryogenic heat exchanger is also very important. As discussed throughout the report, building a retrofit plant significantly reduces the capital investment requirement. For example, Cove Point already has transportation, storage and some treatment facilities in place thus allowing for a very attractive overall IRR for the project. Based on the work in this report three main recommendations for building a profitable LNG plant.

11.2 Recommendations

1. Locate the plant next to an abundant water source (or the plant *must* use air instead of water as a cooling fluid)
2. Select optimal mixed refrigerant in MCHE
3. Use existing facility in retrofit capacity if at all possible

Section 12

Acknowledgements

We would like to Professor Fabiano for his help through the past five months as well as our faculty advisor, Dr. Holleran. We would also like to thank all of the other industrial consultants who so kindly and enthusiastically volunteered their time to meet with us each week to work through a variety of problems we encountered along the way.

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Section 13

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Section 14

Appendices

Appendix A: Original Problem Statement

Export of Marcellus Shale LNG

Proposed by Ann Hewitt, Steven Lee, Ryan Marschang, and Tyler Moeller

September 6, 2013

Overview

The Marcellus Shale natural gas field that spans from West Virginia to New York is leading the recent surge in domestic energy production, with the United States government predicting that the U.S. will be a liquefied natural gas (LNG) exporter by 2016.[1] This development has prompted the need for more LNG export facilities in the U.S. An inactive LNG import facility, Dominion Cove Point LNG in Maryland has the necessary infrastructure to transport natural gas from the Marcellus Shale and could be retrofitted to export LNG to locations around the world.[2]

Description

The Marcellus Shale field contains an estimated 177 trillion cubic feet of natural gas according to conservative estimates, with the actual total likely much higher. Companies continue to look for efficient, cost-effective ways of transferring this fuel to profitable locations, extending across the country and beyond. The most feasible option for transporting natural gas farther than 1,500 km is as LNG, which is created through a series of processes involving removal of water and contaminants, liquefaction, refrigeration, and storage before eventual transportation.[3]

The project involves designing an LNG facility to convert Marcellus Shale natural gas for export to global markets. Existing pipeline infrastructure is in place for a facility on the East Coast. Using materials and knowledge gained from the chemical engineering curriculum, the team will design a liquefaction process consisting of multiple stages, including pre-feed processing, liquefaction (refrigeration cycle), storage, product loading, and transportation. An efficient method of liquefaction to be considered is the Cascade process.[4]

A comparison of feasible LNG plant designs will be necessary. Floating LNG facilities are one alternative to traditional onshore plants. Another option is the retrofitting of the Dominion Cove Point LNG plant, which is currently set up to import but could be converted to an export facility. This project envisions an extensive analysis of the conversion from import to export, which will be considered along with an appropriate process design of gas liquefaction.

In addition to a strong technical foundation and design, this project will also investigate the economics of the various plant possibilities. Determining the costs to produce, liquefy, and transport the LNG will elucidate whether the cost to retrofit the Cove Point facility is feasible from a financial standpoint, beyond its technical merits. The economic advantage of converting the Cove Point facility is that the LNG tankage, port, and other infrastructure is already in place, likely resulting in a lower capital investment compared to building a new LNG export facility from scratch.

Furthermore, this project will inspect the economics of exporting Marcellus Shale gas. With the recent closure of the vast majority of nuclear power plants in Japan, the nation is more reliant now than ever before on imported natural gas to satisfy its energy needs. In 2012, United States natural gas (NG) prices were at 2.76 $/mmbtu and Japan LNG prices were at 16.75

$/mmbtu in 2012, presenting a large U.S. economic opportunity for successful LNG production and export.[5] This project will present an economic analysis of a chemical process involving the costs of constructing and operating an LNG facility and distribution to a market where LNG is in high demand. The LNG markets in other countries are often locked into long term contracts, unlike the natural gas market in the U.S., and this project will allow for the exploration of the current LNG financial landscape.

Key Points of Proposal:

- Design and construction of an LNG export plant based on a retrofit of an existing import facility with infrastructure to use Marcellus Shale gas as the feed.
- Evaluation of different LNG processes/technologies with consideration for possible improvements and explanation of why converting an import facility into an export facility is cheaper than starting from scratch.
- Evaluation of the economics involved in the decision to build an LNG plant.

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Appendix B: Aspen Simulation Input/Report Summary

```
<< All Blocks Reinitialized >>


<< Run reinitialized 22:31:44 Mon Apr 7, 2014>>



->Processing input specifications ...

  Flowsheet Analysis :

 Block $OLVER01 (Method: WEGSTEIN) has been defined to converge
         streams: P3        MR8

 COMPUTATION ORDER FOR THE FLOWSHEET:
 $OLVER01 F5 $CHX1H02 $CHX2H02 T2 $CHX1H01 T1 PHX1 F1 SPLIT
 |  V2 PHX2 F2 V3 PHX3 $CHX1H03 $CHX2H01 $CHX2HTR MIX
 |  $CHX1HTR C6 MHT1 C7 MHT2 V4 MHX1 F3 V5 MHX2 F4 V6 MHX3
 |  C2 C3 C4 C5 PHT V1
 (RETURN $OLVER01)
 V7

->Calculations begin ...


> Beginning Convergence Loop $OLVER01 Method: WEGSTEIN
  Converging tear streams: P3        MR8

   Block: F5       Model: FLASH2

   Block: $CHX1H02 Model: HEATER

   Block: $CHX2H02 Model: HEATER

   Block: T2       Model: COMPR
  *   WARNING
      FEED STREAM IS BELOW DEW POINT


   Block: $CHX1H01 Model: HEATER

   Block: T1       Model: COMPR
  *   WARNING
      FEED STREAM IS BELOW DEW POINT


   Block: PHX1     Model: HEATX

   Block: F1       Model: FLASH2
```

```
Block: SPLIT    Model: FSPLIT
Block: V2       Model: VALVE
Block: PHX2     Model: HEATX
Block: F2       Model: FLASH2
Block: V3       Model: VALVE
Block: PHX3     Model: HEATX
Block: $CHX1H03 Model: HEATER
Block: $CHX2H01 Model: HEATER
Block: $CHX2HTR Model: MHEATER
Block: MIX      Model: MIXER
Block: $CHX1HTR Model: MHEATER
Block: C6       Model: COMPR
Block: MHT1     Model: HEATER
Block: C7       Model: COMPR
Block: MHT2     Model: HEATER
Block: V4       Model: VALVE
Block: MHX1     Model: HEATX
Block: F3       Model: FLASH2
Block: V5       Model: VALVE
Block: MHX2     Model: HEATX
Block: F4       Model: FLASH2
Block: V6       Model: VALVE
Block: MHX3     Model: HEATX
Block: C2       Model: COMPR
Block: C3       Model: COMPR
Block: C4       Model: COMPR
```

```
 Block: C5       Model: COMPR

 Block: PHT      Model: HEATER

 Block: V1       Model: VALVE

> Loop $OLVER01 Method: WEGSTEIN     Iteration    1
  Converging tear streams: P3        MR8
   3 vars not converged, Max Err/Tol  -0.12307E+04

 Block: F5       Model: FLASH2

 Block: $CHX1H02 Model: HEATER

 Block: $CHX2H02 Model: HEATER

 Block: T2       Model: COMPR
  *   WARNING
      FEED STREAM IS BELOW DEW POINT


 Block: $CHX1H01 Model: HEATER

 Block: T1       Model: COMPR
  *   WARNING
      FEED STREAM IS BELOW DEW POINT


 Block: PHX1     Model: HEATX

 Block: F1       Model: FLASH2

 Block: SPLIT    Model: FSPLIT

 Block: V2       Model: VALVE

 Block: PHX2     Model: HEATX

 Block: F2       Model: FLASH2

 Block: V3       Model: VALVE

 Block: PHX3     Model: HEATX

 Block: $CHX1H03 Model: HEATER

 Block: $CHX2H01 Model: HEATER

 Block: $CHX2HTR Model: MHEATER

 Block: MIX      Model: MIXER
```

```
   Block: $CHX1HTR Model: MHEATER

   Block: C6       Model: COMPR

   Block: MHT1     Model: HEATER

   Block: C7       Model: COMPR

   Block: MHT2     Model: HEATER

   Block: V4       Model: VALVE

   Block: MHX1     Model: HEATX

   Block: F3       Model: FLASH2

   Block: V5       Model: VALVE

   Block: MHX2     Model: HEATX

   Block: F4       Model: FLASH2

   Block: V6       Model: VALVE

   Block: MHX3     Model: HEATX

   Block: C2       Model: COMPR

   Block: C3       Model: COMPR

   Block: C4       Model: COMPR

   Block: C5       Model: COMPR

   Block: PHT      Model: HEATER

   Block: V1       Model: VALVE

> Loop $OLVER01 Method: WEGSTEIN     Iteration    2
  Converging tear streams: P3        MR8
# Converged              Max Err/Tol  -0.41924E-03

   Block: V7       Model: VALVE

->Generating block results ...

    Block: PHX1     Model: HEATX

    Block: PHX2     Model: HEATX

    Block: PHX3     Model: HEATX
```

```
    Block: PHT      Model: HEATER

    Block: MHT2     Model: HEATER

    Block: MHT1     Model: HEATER

    Block: MHX1     Model: HEATX

    Block: MHX2     Model: HEATX

    Block: MHX3     Model: HEATX

    Block: $CHX1HTR Model: MHEATER

    Block: $CHX2HTR Model: MHEATER

->Simulation calculations completed ...


  ***  No Warnings were issued during Input Translation ***


             ***  Summary of Simulation Errors  ***

                  Physical
                  Property         System        Simulation
  Terminal Errors     0               0               0
    Severe Errors     0               0               0
           Errors     0               0               0
         Warnings     0               0               4

<< Loading Simulation Engine 10:12:52 Tue Apr 8, 2014>>

<set objective = None>
```

```
 BLOCK:  CHX1     MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 MRA1             MRA2
                 MRB1             MRB2
                 NG4              NG5

   COLD SIDE:    INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 MRAB             MR1

   PROPERTIES FOR STREAM MRA1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM NG4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRAB
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           389353.         389353.
0.00000
       MASS(LB/HR   )          0.940482E+07    0.940482E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.142112E+11   -0.142112E+11
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.820761E+08  LB/HR
    PRODUCT STREAMS CO2E         0.820761E+08  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  ***


   SPECIFICATIONS FOR STREAM MRA1    :
```

```
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                       -
170.000
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRB1    :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                       -
170.000
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM NG4     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                       -
170.000
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRAB    :
   TWO    PHASE      FLASH
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

                         ***  RESULTS  ***

  INLET                  OUTLET       OUTLET       OUTLET
  STREAM    DUTY         TEMPERATURE  PRESSURE     VAPOR FRAC
            BTU/HR       F            PSIA

  MRA1      -0.22319E+09   -170.00      600.00        0.0000
  MRB1      -0.29531E+09   -170.00      600.00        0.0000
  NG4       -0.30192E+09   -170.00      720.00        0.0000
  MRAB       0.82042E+09    -57.87      49.000        1.0000


         ------------------------------------------
         |                                        |
  MRA1   |                                        | MRA2
 --------->|         81487.     LBMOL/HR          |--------->
    -29.00 |                                      |  -170.00
         |                                        |
  MRB1   |                                        | MRB2
```

```
 --------->|          72221.     LBMOL/HR          |--------->
    -29.00 |                                       |  -170.00
           |                                       |
  NG4      |                                       | NG5
 --------->|          81937.     LBMOL/HR          |--------->
    -29.00 |                                       |  -170.00
           |                                       |
  MR1      |                                       | MRAB
 <---------|        0.15371E+06 LBMOL/HR           |<---------
    -57.87 |                                       |  -192.60
           |                                       |
           -----------------------------------------


                           ***  INTERNAL ANALYSIS  ***

  FLOW IS COUNTERCURRENT.
  DUTY                                 0.82042E+09 BTU/HR
  UA                                   0.64466E+08 BTU/HR-R
  AVERAGE LMTD (DUTY/UA)                12.726     F
  MIN TEMP APPROACH                     6.2279     F
  HOT-SIDE TEMP APPROACH                28.865     F
  COLD-SIDE TEMP APPROACH               22.608     F
  HOT-SIDE NTU                          11.079
  COLD-SIDE NTU                         10.587

  DUTY           T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F          F         F          F     BTU/HR-R
BTU/HR      BTU/HR-R

   0.000       -170.00   -192.60     22.61
  0.8204E+07   -167.99   -190.69     22.70     22.65  0.3622E+06
0.8204E+07  0.3622E+06
  0.1641E+08   -166.00   -188.74     22.74     22.72  0.3611E+06
0.8204E+07  0.7233E+06
  0.2461E+08   -164.02   -186.75     22.73     22.73  0.3609E+06
0.8204E+07  0.1084E+07
  0.3282E+08   -162.05   -184.73     22.68     22.70  0.3614E+06
0.8204E+07  0.1446E+07
  0.4102E+08   -160.09   -182.68     22.59     22.63  0.3625E+06
0.8204E+07  0.1808E+07
  0.4923E+08   -158.15   -180.61     22.46     22.52  0.3642E+06
0.8204E+07  0.2172E+07
  0.5743E+08   -156.22   -178.53     22.31     22.39  0.3665E+06
0.8204E+07  0.2539E+07
  0.6563E+08   -154.31   -176.43     22.13     22.22  0.3692E+06
0.8204E+07  0.2908E+07
```

```
  0.7384E+08   -152.40   -174.34     21.94     22.03  0.3723E+06
0.8204E+07  0.3280E+07
  0.7578E+08   -151.95   -173.85     21.89     21.92  0.8842E+05
0.1938E+07  0.3369E+07          BP  MRB1
  0.8204E+08   -150.80   -172.25     21.44     21.67  0.2892E+06
0.6266E+07  0.3658E+07
  0.9025E+08   -149.32   -170.17     20.84     21.14  0.3880E+06
0.8204E+07  0.4046E+07
  0.9845E+08   -147.85   -168.10     20.25     20.54  0.3994E+06
0.8204E+07  0.4445E+07
  0.1067E+09   -146.39   -166.04     19.66     19.95  0.4112E+06
0.8204E+07  0.4857E+07
  0.1149E+09   -144.93   -164.01     19.08     19.37  0.4236E+06
0.8204E+07  0.5280E+07
  0.1231E+09   -143.49   -162.01     18.52     18.80  0.4364E+06
0.8204E+07  0.5717E+07
  0.1313E+09   -142.06   -160.03     17.98     18.25  0.4496E+06
0.8204E+07  0.6166E+07
  0.1395E+09   -140.63   -158.09     17.46     17.72  0.4631E+06
0.8204E+07  0.6629E+07
  0.1477E+09   -139.22   -156.18     16.96     17.21  0.4768E+06
0.8204E+07  0.7106E+07
  0.1559E+09   -137.81   -154.30     16.49     16.72  0.4907E+06
0.8204E+07  0.7597E+07
  0.1641E+09   -136.42   -152.46     16.04     16.26  0.5046E+06
0.8204E+07  0.8101E+07
  0.1723E+09   -135.03   -150.65     15.62     15.83  0.5184E+06
0.8204E+07  0.8620E+07
  0.1805E+09   -133.65   -148.88     15.23     15.42  0.5320E+06
0.8204E+07  0.9152E+07
  0.1887E+09   -132.28   -147.15     14.86     15.04  0.5453E+06
0.8204E+07  0.9697E+07
  0.1969E+09   -130.92   -145.45     14.53     14.70  0.5583E+06
0.8204E+07  0.1026E+08
  0.2051E+09   -129.57   -143.79     14.22     14.38  0.5707E+06
0.8204E+07  0.1083E+08
  0.2133E+09   -128.22   -142.16     13.95     14.08  0.5825E+06
0.8204E+07  0.1141E+08
  0.2215E+09   -126.88   -140.57     13.70     13.82  0.5936E+06
0.8204E+07  0.1200E+08
  0.2297E+09   -125.54   -139.01     13.47     13.58  0.6040E+06
0.8204E+07  0.1261E+08
  0.2379E+09   -124.22   -137.49     13.27     13.37  0.6135E+06
0.8204E+07  0.1322E+08
  0.2461E+09   -122.90   -136.00     13.10     13.19  0.6222E+06
0.8204E+07  0.1384E+08
  0.2543E+09   -121.59   -134.53     12.94     13.02  0.6302E+06
0.8204E+07  0.1447E+08
  0.2625E+09   -120.29   -133.10     12.81     12.87  0.6374E+06
0.8204E+07  0.1511E+08
  0.2707E+09   -119.00   -131.69     12.69     12.75  0.6436E+06
0.8204E+07  0.1575E+08
```

```
  0.2789E+09   -117.72   -130.31     12.59     12.64  0.6490E+06
0.8204E+07  0.1640E+08
  0.2871E+09   -116.46   -128.96     12.50     12.55  0.6539E+06
0.8204E+07  0.1706E+08
  0.2954E+09   -115.21   -127.63     12.43     12.47  0.6582E+06
0.8204E+07  0.1771E+08
  0.3036E+09   -113.97   -126.33     12.35     12.39  0.6622E+06
0.8204E+07  0.1838E+08

  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.3118E+09   -112.76   -125.04     12.28     12.32  0.6661E+06
0.8204E+07  0.1904E+08
  0.3200E+09   -111.57   -123.78     12.21     12.24  0.6700E+06
0.8204E+07  0.1971E+08
  0.3282E+09   -110.41   -122.53     12.12     12.16  0.6744E+06
0.8204E+07  0.2039E+08
  0.3364E+09   -109.28   -121.31     12.02     12.07  0.6795E+06
0.8204E+07  0.2107E+08
  0.3446E+09   -108.20   -120.10     11.90     11.96  0.6858E+06
0.8204E+07  0.2175E+08
  0.3528E+09   -107.15   -118.91     11.75     11.83  0.6936E+06
0.8204E+07  0.2245E+08
  0.3610E+09   -106.17   -117.73     11.56     11.66  0.7037E+06
0.8204E+07  0.2315E+08
  0.3692E+09   -105.24   -116.56     11.32     11.44  0.7170E+06
0.8204E+07  0.2387E+08
  0.3736E+09   -104.77   -115.94     11.17     11.24  0.3957E+06
0.4450E+07  0.2426E+08         BP  NG4
  0.3774E+09   -104.58   -115.41     10.83     11.00  0.3414E+06
0.3755E+07  0.2460E+08
  0.3856E+09   -104.14   -114.27     10.13     10.48  0.7830E+06
0.8204E+07  0.2539E+08
  0.3938E+09   -103.66   -113.14      9.48      9.80  0.8369E+06
0.8204E+07  0.2622E+08
  0.4020E+09   -103.14   -112.02      8.88      9.18  0.8939E+06
0.8204E+07  0.2712E+08
  0.4102E+09   -102.57   -110.91      8.34      8.61  0.9531E+06
0.8204E+07  0.2807E+08
  0.4184E+09   -101.94   -109.80      7.86      8.10  0.1013E+07
0.8204E+07  0.2908E+08
  0.4266E+09   -101.27   -108.71      7.44      7.65  0.1073E+07
0.8204E+07  0.3016E+08
  0.4348E+09   -100.54   -107.61      7.08      7.26  0.1131E+07
0.8204E+07  0.3129E+08
  0.4430E+09    -99.75   -106.53      6.78      6.93  0.1184E+07
0.8204E+07  0.3247E+08
```

```
  0.4512E+09    -98.90   -105.45       6.55       6.66  0.1232E+07
0.8204E+07  0.3370E+08
  0.4594E+09    -98.00   -104.37       6.38       6.46  0.1270E+07
0.8204E+07  0.3497E+08
  0.4676E+09    -97.03   -103.30       6.27       6.32  0.1297E+07
0.8204E+07  0.3627E+08
  0.4758E+09    -96.00   -102.23       6.23       6.25  0.1313E+07
0.8204E+07  0.3758E+08  GBL
  0.4840E+09    -94.92   -101.17       6.25       6.24  0.1315E+07
0.8204E+07  0.3890E+08
  0.4923E+09    -93.79   -100.10       6.32       6.28  0.1306E+07
0.8204E+07  0.4020E+08
  0.5005E+09    -92.60    -99.04       6.44       6.38  0.1286E+07
0.8204E+07  0.4149E+08
  0.5087E+09    -91.37    -97.99       6.62       6.53  0.1256E+07
0.8204E+07  0.4275E+08
  0.5169E+09    -90.09    -96.93       6.84       6.73  0.1219E+07
0.8204E+07  0.4397E+08
  0.5237E+09    -89.00    -96.06       7.05       6.95  0.9790E+06
0.6801E+07  0.4494E+08         DP  NG4
  0.5251E+09    -88.76    -95.88       7.12       7.09  0.1980E+06
0.1403E+07  0.4514E+08
  0.5333E+09    -87.31    -94.83       7.52       7.32  0.1121E+07
0.8204E+07  0.4626E+08
  0.5415E+09    -85.83    -93.78       7.95       7.73  0.1061E+07
0.8204E+07  0.4733E+08
  0.5497E+09    -84.33    -92.74       8.41       8.18  0.1003E+07
0.8204E+07  0.4833E+08
  0.5579E+09    -82.79    -91.70       8.90       8.65  0.9480E+06
0.8204E+07  0.4928E+08
  0.5661E+09    -81.24    -90.66       9.42       9.16  0.8959E+06
0.8204E+07  0.5017E+08
  0.5743E+09    -79.67    -89.63       9.96       9.68  0.8472E+06
0.8204E+07  0.5102E+08
  0.5825E+09    -78.08    -88.60      10.52      10.23  0.8018E+06
0.8204E+07  0.5182E+08
  0.5907E+09    -76.48    -87.58      11.10      10.80  0.7595E+06
0.8204E+07  0.5258E+08
  0.5989E+09    -74.86    -86.56      11.69      11.39  0.7202E+06
0.8204E+07  0.5330E+08
  0.6071E+09    -73.24    -85.55      12.31      12.00  0.6837E+06
0.8204E+07  0.5399E+08
  0.6153E+09    -71.60    -84.54      12.94      12.62  0.6499E+06
0.8204E+07  0.5463E+08
  0.6235E+09    -69.95    -83.54      13.59      13.26  0.6185E+06
0.8204E+07  0.5525E+08
  0.6317E+09    -68.29    -82.55      14.26      13.92  0.5893E+06
0.8204E+07  0.5584E+08
  0.6399E+09    -66.63    -81.57      14.94      14.60  0.5621E+06
0.8204E+07  0.5640E+08
  0.6481E+09    -64.96    -80.60      15.63      15.28  0.5368E+06
0.8204E+07  0.5694E+08
```

```
  0.6563E+09    -63.29    -79.63     16.34     15.99  0.5132E+06
0.8204E+07  0.5745E+08
  0.6645E+09    -61.60    -78.67     17.07     16.70  0.4911E+06
0.8204E+07  0.5795E+08
  0.6727E+09    -59.92    -77.73     17.81     17.44  0.4705E+06
0.8204E+07  0.5842E+08
  0.6810E+09    -58.23    -76.79     18.56     18.18  0.4512E+06
0.8204E+07  0.5887E+08
  0.6892E+09    -56.53    -75.87     19.33     18.95  0.4330E+06
0.8204E+07  0.5930E+08
  0.6974E+09    -54.84    -74.95     20.12     19.72  0.4160E+06
0.8204E+07  0.5972E+08

  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE      Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.7056E+09    -53.13    -74.05     20.91     20.51  0.4000E+06
0.8204E+07  0.6012E+08
  0.7138E+09    -51.43    -73.16     21.73     21.32  0.3848E+06
0.8204E+07  0.6050E+08
  0.7220E+09    -49.72    -72.28     22.56     22.14  0.3706E+06
0.8204E+07  0.6087E+08
  0.7302E+09    -48.01    -71.41     23.40     22.97  0.3571E+06
0.8204E+07  0.6123E+08
  0.7384E+09    -46.30    -70.55     24.25     23.82  0.3444E+06
0.8204E+07  0.6157E+08
  0.7466E+09    -44.58    -69.70     25.13     24.69  0.3323E+06
0.8204E+07  0.6191E+08
  0.7548E+09    -42.86    -68.87     26.01     25.57  0.3209E+06
0.8204E+07  0.6223E+08
  0.7630E+09    -41.13    -68.05     26.92     26.46  0.3100E+06
0.8204E+07  0.6254E+08
  0.7712E+09    -39.41    -67.24     27.83     27.37  0.2997E+06
0.8204E+07  0.6284E+08
  0.7794E+09    -37.68    -66.44     28.77     28.30  0.2899E+06
0.8204E+07  0.6313E+08
  0.7876E+09    -35.95    -65.66     29.71     29.24  0.2806E+06
0.8204E+07  0.6341E+08
  0.7958E+09    -34.21    -64.88     30.67     30.19  0.2718E+06
0.8204E+07  0.6368E+08
  0.8040E+09    -32.48    -64.12     31.65     31.16  0.2633E+06
0.8204E+07  0.6394E+08
  0.8116E+09    -30.86    -63.42     32.56     32.10  0.2372E+06
0.7616E+07  0.6418E+08          DP  MRAB
  0.8122E+09    -30.74    -63.05     32.31     32.44  0.1814E+05
0.5885E+06  0.6420E+08
  0.8204E+09    -29.00    -57.87     28.87     30.56  0.2685E+06
0.8204E+07  0.6447E+08
```

```
  GBL = GLOBAL     LOC = LOCAL     DP  = DEW POINT     BP  = BUBBLE
POINT

 BLOCK:  CHX1     MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 MRA1             MRA2
                 MRB1             MRB2
                 NG4              NG5

   COLD SIDE:    INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 MRAB             MR1

   PROPERTIES FOR STREAM MRA1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM NG4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRAB
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            389353.         389353.
0.00000
       MASS(LB/HR   )          0.940482E+07    0.940482E+07
0.00000
       ENTHALPY(BTU/HR  )     -0.142112E+11   -0.142112E+11
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.820761E+08  LB/HR
    PRODUCT STREAMS CO2E         0.820761E+08  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 ***

```
   SPECIFICATIONS FOR STREAM MRA1    :
   TWO    PHASE   TP  FLASH
   SPECIFIED TEMPERATURE             F                      -
170.000
   PRESSURE DROP                     PSI                       0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRB1    :
   TWO    PHASE   TP  FLASH
   SPECIFIED TEMPERATURE             F                      -
170.000
   PRESSURE DROP                     PSI                       0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM NG4     :
   TWO    PHASE   TP  FLASH
   SPECIFIED TEMPERATURE             F                      -
170.000
   PRESSURE DROP                     PSI                       0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRAB    :
   TWO    PHASE       FLASH
   PRESSURE DROP                     PSI                       0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE
0.000100000
```

*** RESULTS ***

INLET STREAM	DUTY BTU/HR	OUTLET TEMPERATURE F	OUTLET PRESSURE PSIA	OUTLET VAPOR FRAC
MRA1	-0.22319E+09	-170.00	600.00	0.0000
MRB1	-0.29531E+09	-170.00	600.00	0.0000
NG4	-0.30192E+09	-170.00	720.00	0.0000
MRAB	0.82042E+09	-57.87	49.000	1.0000

```
          ------------------------------------------
          |                                        |
```

```
  MRA1      |                                         | MRA2
 --------->|          81487.     LBMOL/HR             |--------->
    -29.00 |                                         |  -170.00
           |                                         |
  MRB1      |                                         | MRB2
 --------->|          72221.     LBMOL/HR             |--------->
    -29.00 |                                         |  -170.00
           |                                         |
  NG4       |                                         | NG5
 --------->|          81937.     LBMOL/HR             |--------->
    -29.00 |                                         |  -170.00
           |                                         |
  MR1       |                                         | MRAB
 <---------|         0.15371E+06 LBMOL/HR             |<---------
    -57.87 |                                         |  -192.60
           |                                         |
           -------------------------------------------
```

```
                        ***  INTERNAL ANALYSIS  ***

  FLOW IS COUNTERCURRENT.
  DUTY                                  0.82042E+09 BTU/HR
  UA                                    0.64466E+08 BTU/HR-R
  AVERAGE LMTD (DUTY/UA)                 12.726     F
  MIN TEMP APPROACH                      6.2279     F
  HOT-SIDE TEMP APPROACH                 28.865     F
  COLD-SIDE TEMP APPROACH                22.608     F
  HOT-SIDE NTU                           11.079
  COLD-SIDE NTU                          10.587

  DUTY           T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA           PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

   0.000       -170.00   -192.60     22.61
  0.8204E+07   -167.99   -190.69     22.70     22.65  0.3622E+06
0.8204E+07  0.3622E+06
  0.1641E+08   -166.00   -188.74     22.74     22.72  0.3611E+06
0.8204E+07  0.7233E+06
  0.2461E+08   -164.02   -186.75     22.73     22.73  0.3609E+06
0.8204E+07  0.1084E+07
  0.3282E+08   -162.05   -184.73     22.68     22.70  0.3614E+06
0.8204E+07  0.1446E+07
  0.4102E+08   -160.09   -182.68     22.59     22.63  0.3625E+06
0.8204E+07  0.1808E+07
  0.4923E+08   -158.15   -180.61     22.46     22.52  0.3642E+06
0.8204E+07  0.2172E+07
```

0.5743E+08 -156.22 -178.53 22.31 22.39 0.3665E+06
0.8204E+07 0.2539E+07
0.6563E+08 -154.31 -176.43 22.13 22.22 0.3692E+06
0.8204E+07 0.2908E+07
0.7384E+08 -152.40 -174.34 21.94 22.03 0.3723E+06
0.8204E+07 0.3280E+07
0.7578E+08 -151.95 -173.85 21.89 21.92 0.8842E+05
0.1938E+07 0.3369E+07 BP MRB1
0.8204E+08 -150.80 -172.25 21.44 21.67 0.2892E+06
0.6266E+07 0.3658E+07
0.9025E+08 -149.32 -170.17 20.84 21.14 0.3880E+06
0.8204E+07 0.4046E+07
0.9845E+08 -147.85 -168.10 20.25 20.54 0.3994E+06
0.8204E+07 0.4445E+07
0.1067E+09 -146.39 -166.04 19.66 19.95 0.4112E+06
0.8204E+07 0.4857E+07
0.1149E+09 -144.93 -164.01 19.08 19.37 0.4236E+06
0.8204E+07 0.5280E+07
0.1231E+09 -143.49 -162.01 18.52 18.80 0.4364E+06
0.8204E+07 0.5717E+07
0.1313E+09 -142.06 -160.03 17.98 18.25 0.4496E+06
0.8204E+07 0.6166E+07
0.1395E+09 -140.63 -158.09 17.46 17.72 0.4631E+06
0.8204E+07 0.6629E+07
0.1477E+09 -139.22 -156.18 16.96 17.21 0.4768E+06
0.8204E+07 0.7106E+07
0.1559E+09 -137.81 -154.30 16.49 16.72 0.4907E+06
0.8204E+07 0.7597E+07
0.1641E+09 -136.42 -152.46 16.04 16.26 0.5046E+06
0.8204E+07 0.8101E+07
0.1723E+09 -135.03 -150.65 15.62 15.83 0.5184E+06
0.8204E+07 0.8620E+07
0.1805E+09 -133.65 -148.88 15.23 15.42 0.5320E+06
0.8204E+07 0.9152E+07
0.1887E+09 -132.28 -147.15 14.86 15.04 0.5453E+06
0.8204E+07 0.9697E+07
0.1969E+09 -130.92 -145.45 14.53 14.70 0.5583E+06
0.8204E+07 0.1026E+08
0.2051E+09 -129.57 -143.79 14.22 14.38 0.5707E+06
0.8204E+07 0.1083E+08
0.2133E+09 -128.22 -142.16 13.95 14.08 0.5825E+06
0.8204E+07 0.1141E+08
0.2215E+09 -126.88 -140.57 13.70 13.82 0.5936E+06
0.8204E+07 0.1200E+08
0.2297E+09 -125.54 -139.01 13.47 13.58 0.6040E+06
0.8204E+07 0.1261E+08
0.2379E+09 -124.22 -137.49 13.27 13.37 0.6135E+06
0.8204E+07 0.1322E+08
0.2461E+09 -122.90 -136.00 13.10 13.19 0.6222E+06
0.8204E+07 0.1384E+08
0.2543E+09 -121.59 -134.53 12.94 13.02 0.6302E+06
0.8204E+07 0.1447E+08

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  0.2625E+09   -120.29   -133.10     12.81     12.87  0.6374E+06
0.8204E+07  0.1511E+08
  0.2707E+09   -119.00   -131.69     12.69     12.75  0.6436E+06
0.8204E+07  0.1575E+08
  0.2789E+09   -117.72   -130.31     12.59     12.64  0.6490E+06
0.8204E+07  0.1640E+08
  0.2871E+09   -116.46   -128.96     12.50     12.55  0.6539E+06
0.8204E+07  0.1706E+08
  0.2954E+09   -115.21   -127.63     12.43     12.47  0.6582E+06
0.8204E+07  0.1771E+08
  0.3036E+09   -113.97   -126.33     12.35     12.39  0.6622E+06
0.8204E+07  0.1838E+08

  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE      Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.3118E+09   -112.76   -125.04     12.28     12.32  0.6661E+06
0.8204E+07  0.1904E+08
  0.3200E+09   -111.57   -123.78     12.21     12.24  0.6700E+06
0.8204E+07  0.1971E+08
  0.3282E+09   -110.41   -122.53     12.12     12.16  0.6744E+06
0.8204E+07  0.2039E+08
  0.3364E+09   -109.28   -121.31     12.02     12.07  0.6795E+06
0.8204E+07  0.2107E+08
  0.3446E+09   -108.20   -120.10     11.90     11.96  0.6858E+06
0.8204E+07  0.2175E+08
  0.3528E+09   -107.15   -118.91     11.75     11.83  0.6936E+06
0.8204E+07  0.2245E+08
  0.3610E+09   -106.17   -117.73     11.56     11.66  0.7037E+06
0.8204E+07  0.2315E+08
  0.3692E+09   -105.24   -116.56     11.32     11.44  0.7170E+06
0.8204E+07  0.2387E+08
  0.3736E+09   -104.77   -115.94     11.17     11.24  0.3957E+06
0.4450E+07  0.2426E+08         BP  NG4
  0.3774E+09   -104.58   -115.41     10.83     11.00  0.3414E+06
0.3755E+07  0.2460E+08
  0.3856E+09   -104.14   -114.27     10.13     10.48  0.7830E+06
0.8204E+07  0.2539E+08
  0.3938E+09   -103.66   -113.14      9.48      9.80  0.8369E+06
0.8204E+07  0.2622E+08
  0.4020E+09   -103.14   -112.02      8.88      9.18  0.8939E+06
0.8204E+07  0.2712E+08
  0.4102E+09   -102.57   -110.91      8.34      8.61  0.9531E+06
0.8204E+07  0.2807E+08
  0.4184E+09   -101.94   -109.80      7.86      8.10  0.1013E+07
0.8204E+07  0.2908E+08
  0.4266E+09   -101.27   -108.71      7.44      7.65  0.1073E+07
0.8204E+07  0.3016E+08
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  0.4348E+09   -100.54   -107.61      7.08      7.26  0.1131E+07
0.8204E+07  0.3129E+08
  0.4430E+09    -99.75   -106.53      6.78      6.93  0.1184E+07
0.8204E+07  0.3247E+08
  0.4512E+09    -98.90   -105.45      6.55      6.66  0.1232E+07
0.8204E+07  0.3370E+08
  0.4594E+09    -98.00   -104.37      6.38      6.46  0.1270E+07
0.8204E+07  0.3497E+08
  0.4676E+09    -97.03   -103.30      6.27      6.32  0.1297E+07
0.8204E+07  0.3627E+08
  0.4758E+09    -96.00   -102.23      6.23      6.25  0.1313E+07
0.8204E+07  0.3758E+08  GBL
  0.4840E+09    -94.92   -101.17      6.25      6.24  0.1315E+07
0.8204E+07  0.3890E+08
  0.4923E+09    -93.79   -100.10      6.32      6.28  0.1306E+07
0.8204E+07  0.4020E+08
  0.5005E+09    -92.60    -99.04      6.44      6.38  0.1286E+07
0.8204E+07  0.4149E+08
  0.5087E+09    -91.37    -97.99      6.62      6.53  0.1256E+07
0.8204E+07  0.4275E+08
  0.5169E+09    -90.09    -96.93      6.84      6.73  0.1219E+07
0.8204E+07  0.4397E+08
  0.5237E+09    -89.00    -96.06      7.05      6.95  0.9790E+06
0.6801E+07  0.4494E+08         DP  NG4
  0.5251E+09    -88.76    -95.88      7.12      7.09  0.1980E+06
0.1403E+07  0.4514E+08
  0.5333E+09    -87.31    -94.83      7.52      7.32  0.1121E+07
0.8204E+07  0.4626E+08
  0.5415E+09    -85.83    -93.78      7.95      7.73  0.1061E+07
0.8204E+07  0.4733E+08
  0.5497E+09    -84.33    -92.74      8.41      8.18  0.1003E+07
0.8204E+07  0.4833E+08
  0.5579E+09    -82.79    -91.70      8.90      8.65  0.9480E+06
0.8204E+07  0.4928E+08
  0.5661E+09    -81.24    -90.66      9.42      9.16  0.8959E+06
0.8204E+07  0.5017E+08
  0.5743E+09    -79.67    -89.63      9.96      9.68  0.8472E+06
0.8204E+07  0.5102E+08
  0.5825E+09    -78.08    -88.60     10.52     10.23  0.8018E+06
0.8204E+07  0.5182E+08
  0.5907E+09    -76.48    -87.58     11.10     10.80  0.7595E+06
0.8204E+07  0.5258E+08
  0.5989E+09    -74.86    -86.56     11.69     11.39  0.7202E+06
0.8204E+07  0.5330E+08
  0.6071E+09    -73.24    -85.55     12.31     12.00  0.6837E+06
0.8204E+07  0.5399E+08
  0.6153E+09    -71.60    -84.54     12.94     12.62  0.6499E+06
0.8204E+07  0.5463E+08
  0.6235E+09    -69.95    -83.54     13.59     13.26  0.6185E+06
0.8204E+07  0.5525E+08
  0.6317E+09    -68.29    -82.55     14.26     13.92  0.5893E+06
0.8204E+07  0.5584E+08
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  0.6399E+09    -66.63    -81.57     14.94     14.60  0.5621E+06
0.8204E+07  0.5640E+08
  0.6481E+09    -64.96    -80.60     15.63     15.28  0.5368E+06
0.8204E+07  0.5694E+08
  0.6563E+09    -63.29    -79.63     16.34     15.99  0.5132E+06
0.8204E+07  0.5745E+08
  0.6645E+09    -61.60    -78.67     17.07     16.70  0.4911E+06
0.8204E+07  0.5795E+08
  0.6727E+09    -59.92    -77.73     17.81     17.44  0.4705E+06
0.8204E+07  0.5842E+08
  0.6810E+09    -58.23    -76.79     18.56     18.18  0.4512E+06
0.8204E+07  0.5887E+08
  0.6892E+09    -56.53    -75.87     19.33     18.95  0.4330E+06
0.8204E+07  0.5930E+08
  0.6974E+09    -54.84    -74.95     20.12     19.72  0.4160E+06
0.8204E+07  0.5972E+08

  DUTY           T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.7056E+09    -53.13    -74.05     20.91     20.51  0.4000E+06
0.8204E+07  0.6012E+08
  0.7138E+09    -51.43    -73.16     21.73     21.32  0.3848E+06
0.8204E+07  0.6050E+08
  0.7220E+09    -49.72    -72.28     22.56     22.14  0.3706E+06
0.8204E+07  0.6087E+08
  0.7302E+09    -48.01    -71.41     23.40     22.97  0.3571E+06
0.8204E+07  0.6123E+08
  0.7384E+09    -46.30    -70.55     24.25     23.82  0.3444E+06
0.8204E+07  0.6157E+08
  0.7466E+09    -44.58    -69.70     25.13     24.69  0.3323E+06
0.8204E+07  0.6191E+08
  0.7548E+09    -42.86    -68.87     26.01     25.57  0.3209E+06
0.8204E+07  0.6223E+08
  0.7630E+09    -41.13    -68.05     26.92     26.46  0.3100E+06
0.8204E+07  0.6254E+08
  0.7712E+09    -39.41    -67.24     27.83     27.37  0.2997E+06
0.8204E+07  0.6284E+08
  0.7794E+09    -37.68    -66.44     28.77     28.30  0.2899E+06
0.8204E+07  0.6313E+08
  0.7876E+09    -35.95    -65.66     29.71     29.24  0.2806E+06
0.8204E+07  0.6341E+08
  0.7958E+09    -34.21    -64.88     30.67     30.19  0.2718E+06
0.8204E+07  0.6368E+08
  0.8040E+09    -32.48    -64.12     31.65     31.16  0.2633E+06
0.8204E+07  0.6394E+08
  0.8116E+09    -30.86    -63.42     32.56     32.10  0.2372E+06
0.7616E+07  0.6418E+08          DP  MRAB
```

```
  0.8122E+09    -30.74    -63.05     32.31     32.44  0.1814E+05
0.5885E+06  0.6420E+08
  0.8204E+09    -29.00    -57.87     28.87     30.56  0.2685E+06
0.8204E+07  0.6447E+08


  GBL = GLOBAL     LOC = LOCAL     DP  = DEW POINT     BP  = BUBBLE
POINT

 BLOCK:  CHX1     MODEL: MHEATX
 ------------------------------

   HOT SIDE:    INLET STREAM     OUTLET STREAM
                ------------     -------------
                MRA1             MRA2
                MRB1             MRB2
                NG4              NG5

   COLD SIDE:   INLET STREAM     OUTLET STREAM
                ------------     -------------
                MRAB             MR1

   PROPERTIES FOR STREAM MRA1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM NG4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRAB
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            389353.         389353.
0.00000
       MASS(LB/HR   )           0.940482E+07    0.940482E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.142112E+11   -0.142112E+11
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.820761E+08  LB/HR
```

```
 PRODUCT STREAMS CO2E          0.820761E+08  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  ***


  SPECIFICATIONS FOR STREAM MRA1    :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE               F                       -
170.000
  PRESSURE DROP                       PSI                       0.0
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE
0.000100000

  SPECIFICATIONS FOR STREAM MRB1    :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE               F                       -
170.000
  PRESSURE DROP                       PSI                       0.0
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE
0.000100000

  SPECIFICATIONS FOR STREAM NG4     :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE               F                       -
170.000
  PRESSURE DROP                       PSI                       0.0
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE
0.000100000

  SPECIFICATIONS FOR STREAM MRAB    :
  TWO    PHASE      FLASH
  PRESSURE DROP                       PSI                       0.0
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE
0.000100000

                    ***  RESULTS  ***

 INLET                  OUTLET       OUTLET       OUTLET
 STREAM    DUTY         TEMPERATURE  PRESSURE     VAPOR FRAC
           BTU/HR       F            PSIA

 MRA1      -0.22319E+09   -170.00      600.00        0.0000
 MRB1      -0.29531E+09   -170.00      600.00        0.0000
 NG4       -0.30192E+09   -170.00      720.00        0.0000
 MRAB       0.82042E+09    -57.87      49.000        1.0000
```

```
          ------------------------------------------
          |                                        |
 MRA1     |                                        | MRA2
--------->|         81487.     LBMOL/HR            |--------->
   -29.00 |                                        |  -170.00
          |                                        |
 MRB1     |                                        | MRB2
--------->|         72221.     LBMOL/HR            |--------->
   -29.00 |                                        |  -170.00
          |                                        |
 NG4      |                                        | NG5
--------->|         81937.     LBMOL/HR            |--------->
   -29.00 |                                        |  -170.00
          |                                        |
 MR1      |                                        | MRAB
<---------|        0.15371E+06 LBMOL/HR            |<---------
   -57.87 |                                        |  -192.60
          |                                        |
          ------------------------------------------
```

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                         ***  INTERNAL ANALYSIS  ***

 FLOW IS COUNTERCURRENT.
 DUTY                                0.82042E+09 BTU/HR
 UA                                  0.64466E+08 BTU/HR-R
 AVERAGE LMTD (DUTY/UA)               12.726      F
 MIN TEMP APPROACH                    6.2279      F
 HOT-SIDE TEMP APPROACH               28.865      F
 COLD-SIDE TEMP APPROACH              22.608      F
 HOT-SIDE NTU                         11.079
 COLD-SIDE NTU                        10.587

 DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
 BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.000       -170.00   -192.60     22.61
 0.8204E+07   -167.99   -190.69     22.70     22.65  0.3622E+06
0.8204E+07  0.3622E+06
 0.1641E+08   -166.00   -188.74     22.74     22.72  0.3611E+06
0.8204E+07  0.7233E+06
 0.2461E+08   -164.02   -186.75     22.73     22.73  0.3609E+06
0.8204E+07  0.1084E+07
 0.3282E+08   -162.05   -184.73     22.68     22.70  0.3614E+06
0.8204E+07  0.1446E+07
```

```
  0.4102E+08   -160.09   -182.68     22.59     22.63  0.3625E+06
0.8204E+07  0.1808E+07
  0.4923E+08   -158.15   -180.61     22.46     22.52  0.3642E+06
0.8204E+07  0.2172E+07
  0.5743E+08   -156.22   -178.53     22.31     22.39  0.3665E+06
0.8204E+07  0.2539E+07
  0.6563E+08   -154.31   -176.43     22.13     22.22  0.3692E+06
0.8204E+07  0.2908E+07
  0.7384E+08   -152.40   -174.34     21.94     22.03  0.3723E+06
0.8204E+07  0.3280E+07
  0.7578E+08   -151.95   -173.85     21.89     21.92  0.8842E+05
0.1938E+07  0.3369E+07          BP  MRB1
  0.8204E+08   -150.80   -172.25     21.44     21.67  0.2892E+06
0.6266E+07  0.3658E+07
  0.9025E+08   -149.32   -170.17     20.84     21.14  0.3880E+06
0.8204E+07  0.4046E+07
  0.9845E+08   -147.85   -168.10     20.25     20.54  0.3994E+06
0.8204E+07  0.4445E+07
  0.1067E+09   -146.39   -166.04     19.66     19.95  0.4112E+06
0.8204E+07  0.4857E+07
  0.1149E+09   -144.93   -164.01     19.08     19.37  0.4236E+06
0.8204E+07  0.5280E+07
  0.1231E+09   -143.49   -162.01     18.52     18.80  0.4364E+06
0.8204E+07  0.5717E+07
  0.1313E+09   -142.06   -160.03     17.98     18.25  0.4496E+06
0.8204E+07  0.6166E+07
  0.1395E+09   -140.63   -158.09     17.46     17.72  0.4631E+06
0.8204E+07  0.6629E+07
  0.1477E+09   -139.22   -156.18     16.96     17.21  0.4768E+06
0.8204E+07  0.7106E+07
  0.1559E+09   -137.81   -154.30     16.49     16.72  0.4907E+06
0.8204E+07  0.7597E+07
  0.1641E+09   -136.42   -152.46     16.04     16.26  0.5046E+06
0.8204E+07  0.8101E+07
  0.1723E+09   -135.03   -150.65     15.62     15.83  0.5184E+06
0.8204E+07  0.8620E+07
  0.1805E+09   -133.65   -148.88     15.23     15.42  0.5320E+06
0.8204E+07  0.9152E+07
  0.1887E+09   -132.28   -147.15     14.86     15.04  0.5453E+06
0.8204E+07  0.9697E+07
  0.1969E+09   -130.92   -145.45     14.53     14.70  0.5583E+06
0.8204E+07  0.1026E+08
  0.2051E+09   -129.57   -143.79     14.22     14.38  0.5707E+06
0.8204E+07  0.1083E+08
  0.2133E+09   -128.22   -142.16     13.95     14.08  0.5825E+06
0.8204E+07  0.1141E+08
  0.2215E+09   -126.88   -140.57     13.70     13.82  0.5936E+06
0.8204E+07  0.1200E+08
  0.2297E+09   -125.54   -139.01     13.47     13.58  0.6040E+06
0.8204E+07  0.1261E+08
  0.2379E+09   -124.22   -137.49     13.27     13.37  0.6135E+06
0.8204E+07  0.1322E+08
```

0.2461E+09	-122.90	-136.00	13.10	13.19	0.6222E+06	0.8204E+07	0.1384E+08	
0.2543E+09	-121.59	-134.53	12.94	13.02	0.6302E+06	0.8204E+07	0.1447E+08	
0.2625E+09	-120.29	-133.10	12.81	12.87	0.6374E+06	0.8204E+07	0.1511E+08	
0.2707E+09	-119.00	-131.69	12.69	12.75	0.6436E+06	0.8204E+07	0.1575E+08	
0.2789E+09	-117.72	-130.31	12.59	12.64	0.6490E+06	0.8204E+07	0.1640E+08	
0.2871E+09	-116.46	-128.96	12.50	12.55	0.6539E+06	0.8204E+07	0.1706E+08	
0.2954E+09	-115.21	-127.63	12.43	12.47	0.6582E+06	0.8204E+07	0.1771E+08	
0.3036E+09	-113.97	-126.33	12.35	12.39	0.6622E+06	0.8204E+07	0.1838E+08	

DUTY	T HOT	T COLD	DELTA T	LMTD	UA ZONE	Q ZONE	UA	PINCH STREAM IN/OUT/DEW/ POINT BUBBLE POINT
BTU/HR	F	F	F	F	BTU/HR-R	BTU/HR	BTU/HR-R	
0.3118E+09	-112.76	-125.04	12.28	12.32	0.6661E+06	0.8204E+07	0.1904E+08	
0.3200E+09	-111.57	-123.78	12.21	12.24	0.6700E+06	0.8204E+07	0.1971E+08	
0.3282E+09	-110.41	-122.53	12.12	12.16	0.6744E+06	0.8204E+07	0.2039E+08	
0.3364E+09	-109.28	-121.31	12.02	12.07	0.6795E+06	0.8204E+07	0.2107E+08	
0.3446E+09	-108.20	-120.10	11.90	11.96	0.6858E+06	0.8204E+07	0.2175E+08	
0.3528E+09	-107.15	-118.91	11.75	11.83	0.6936E+06	0.8204E+07	0.2245E+08	
0.3610E+09	-106.17	-117.73	11.56	11.66	0.7037E+06	0.8204E+07	0.2315E+08	
0.3692E+09	-105.24	-116.56	11.32	11.44	0.7170E+06	0.8204E+07	0.2387E+08	
0.3736E+09	-104.77	-115.94	11.17	11.24	0.3957E+06	0.4450E+07	0.2426E+08	BP NG4
0.3774E+09	-104.58	-115.41	10.83	11.00	0.3414E+06	0.3755E+07	0.2460E+08	
0.3856E+09	-104.14	-114.27	10.13	10.48	0.7830E+06	0.8204E+07	0.2539E+08	
0.3938E+09	-103.66	-113.14	9.48	9.80	0.8369E+06	0.8204E+07	0.2622E+08	
0.4020E+09	-103.14	-112.02	8.88	9.18	0.8939E+06	0.8204E+07	0.2712E+08	
0.4102E+09	-102.57	-110.91	8.34	8.61	0.9531E+06	0.8204E+07	0.2807E+08	

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  0.4184E+09   -101.94   -109.80       7.86       8.10  0.1013E+07
0.8204E+07  0.2908E+08
  0.4266E+09   -101.27   -108.71       7.44       7.65  0.1073E+07
0.8204E+07  0.3016E+08
  0.4348E+09   -100.54   -107.61       7.08       7.26  0.1131E+07
0.8204E+07  0.3129E+08
  0.4430E+09    -99.75   -106.53       6.78       6.93  0.1184E+07
0.8204E+07  0.3247E+08
  0.4512E+09    -98.90   -105.45       6.55       6.66  0.1232E+07
0.8204E+07  0.3370E+08
  0.4594E+09    -98.00   -104.37       6.38       6.46  0.1270E+07
0.8204E+07  0.3497E+08
  0.4676E+09    -97.03   -103.30       6.27       6.32  0.1297E+07
0.8204E+07  0.3627E+08
  0.4758E+09    -96.00   -102.23       6.23       6.25  0.1313E+07
0.8204E+07  0.3758E+08  GBL
  0.4840E+09    -94.92   -101.17       6.25       6.24  0.1315E+07
0.8204E+07  0.3890E+08
  0.4923E+09    -93.79   -100.10       6.32       6.28  0.1306E+07
0.8204E+07  0.4020E+08
  0.5005E+09    -92.60    -99.04       6.44       6.38  0.1286E+07
0.8204E+07  0.4149E+08
  0.5087E+09    -91.37    -97.99       6.62       6.53  0.1256E+07
0.8204E+07  0.4275E+08
  0.5169E+09    -90.09    -96.93       6.84       6.73  0.1219E+07
0.8204E+07  0.4397E+08
  0.5237E+09    -89.00    -96.06       7.05       6.95  0.9790E+06
0.6801E+07  0.4494E+08          DP  NG4
  0.5251E+09    -88.76    -95.88       7.12       7.09  0.1980E+06
0.1403E+07  0.4514E+08
  0.5333E+09    -87.31    -94.83       7.52       7.32  0.1121E+07
0.8204E+07  0.4626E+08
  0.5415E+09    -85.83    -93.78       7.95       7.73  0.1061E+07
0.8204E+07  0.4733E+08
  0.5497E+09    -84.33    -92.74       8.41       8.18  0.1003E+07
0.8204E+07  0.4833E+08
  0.5579E+09    -82.79    -91.70       8.90       8.65  0.9480E+06
0.8204E+07  0.4928E+08
  0.5661E+09    -81.24    -90.66       9.42       9.16  0.8959E+06
0.8204E+07  0.5017E+08
  0.5743E+09    -79.67    -89.63       9.96       9.68  0.8472E+06
0.8204E+07  0.5102E+08
  0.5825E+09    -78.08    -88.60      10.52      10.23  0.8018E+06
0.8204E+07  0.5182E+08
  0.5907E+09    -76.48    -87.58      11.10      10.80  0.7595E+06
0.8204E+07  0.5258E+08
  0.5989E+09    -74.86    -86.56      11.69      11.39  0.7202E+06
0.8204E+07  0.5330E+08
  0.6071E+09    -73.24    -85.55      12.31      12.00  0.6837E+06
0.8204E+07  0.5399E+08
  0.6153E+09    -71.60    -84.54      12.94      12.62  0.6499E+06
0.8204E+07  0.5463E+08
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  0.6235E+09    -69.95    -83.54     13.59     13.26  0.6185E+06
0.8204E+07  0.5525E+08
  0.6317E+09    -68.29    -82.55     14.26     13.92  0.5893E+06
0.8204E+07  0.5584E+08
  0.6399E+09    -66.63    -81.57     14.94     14.60  0.5621E+06
0.8204E+07  0.5640E+08
  0.6481E+09    -64.96    -80.60     15.63     15.28  0.5368E+06
0.8204E+07  0.5694E+08
  0.6563E+09    -63.29    -79.63     16.34     15.99  0.5132E+06
0.8204E+07  0.5745E+08
  0.6645E+09    -61.60    -78.67     17.07     16.70  0.4911E+06
0.8204E+07  0.5795E+08
  0.6727E+09    -59.92    -77.73     17.81     17.44  0.4705E+06
0.8204E+07  0.5842E+08
  0.6810E+09    -58.23    -76.79     18.56     18.18  0.4512E+06
0.8204E+07  0.5887E+08
  0.6892E+09    -56.53    -75.87     19.33     18.95  0.4330E+06
0.8204E+07  0.5930E+08
  0.6974E+09    -54.84    -74.95     20.12     19.72  0.4160E+06
0.8204E+07  0.5972E+08

  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.7056E+09    -53.13    -74.05     20.91     20.51  0.4000E+06
0.8204E+07  0.6012E+08
  0.7138E+09    -51.43    -73.16     21.73     21.32  0.3848E+06
0.8204E+07  0.6050E+08
  0.7220E+09    -49.72    -72.28     22.56     22.14  0.3706E+06
0.8204E+07  0.6087E+08
  0.7302E+09    -48.01    -71.41     23.40     22.97  0.3571E+06
0.8204E+07  0.6123E+08
  0.7384E+09    -46.30    -70.55     24.25     23.82  0.3444E+06
0.8204E+07  0.6157E+08
  0.7466E+09    -44.58    -69.70     25.13     24.69  0.3323E+06
0.8204E+07  0.6191E+08
  0.7548E+09    -42.86    -68.87     26.01     25.57  0.3209E+06
0.8204E+07  0.6223E+08
  0.7630E+09    -41.13    -68.05     26.92     26.46  0.3100E+06
0.8204E+07  0.6254E+08
  0.7712E+09    -39.41    -67.24     27.83     27.37  0.2997E+06
0.8204E+07  0.6284E+08
  0.7794E+09    -37.68    -66.44     28.77     28.30  0.2899E+06
0.8204E+07  0.6313E+08
  0.7876E+09    -35.95    -65.66     29.71     29.24  0.2806E+06
0.8204E+07  0.6341E+08
  0.7958E+09    -34.21    -64.88     30.67     30.19  0.2718E+06
0.8204E+07  0.6368E+08
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  0.8040E+09    -32.48    -64.12     31.65     31.16  0.2633E+06
0.8204E+07  0.6394E+08
  0.8116E+09    -30.86    -63.42     32.56     32.10  0.2372E+06
0.7616E+07  0.6418E+08         DP  MRAB
  0.8122E+09    -30.74    -63.05     32.31     32.44  0.1814E+05
0.5885E+06  0.6420E+08
  0.8204E+09    -29.00    -57.87     28.87     30.56  0.2685E+06
0.8204E+07  0.6447E+08


  GBL = GLOBAL     LOC = LOCAL     DP  = DEW POINT     BP  = BUBBLE
POINT

 BLOCK:  CHX1     MODEL: MHEATX
 ------------------------------

   HOT SIDE:    INLET STREAM     OUTLET STREAM
                ------------     -------------
                MRA1             MRA2
                MRB1             MRB2
                NG4              NG5

   COLD SIDE:   INLET STREAM     OUTLET STREAM
                ------------     -------------
                MRAB             MR1

   PROPERTIES FOR STREAM MRA1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM NG4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRAB
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            389353.         389353.
0.00000
       MASS(LB/HR   )          0.940482E+07    0.940482E+07
0.00000
```

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      ENTHALPY(BTU/HR  )      -0.142112E+11   -0.142112E+11
0.00000

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.820761E+08  LB/HR
    PRODUCT STREAMS CO2E        0.820761E+08  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  ***


   SPECIFICATIONS FOR STREAM MRA1    :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                       -
170.000
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRB1    :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                       -
170.000
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM NG4     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                       -
170.000
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRAB    :
   TWO    PHASE      FLASH
   PRESSURE DROP                      PSI                       0.0
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

                        ***  RESULTS  ***

  INLET                 OUTLET       OUTLET       OUTLET
  STREAM    DUTY        TEMPERATURE  PRESSURE     VAPOR FRAC
            BTU/HR      F            PSIA
```

MRA1	-0.22319E+09	-170.00	600.00	0.0000
MRB1	-0.29531E+09	-170.00	600.00	0.0000
NG4	-0.30192E+09	-170.00	720.00	0.0000
MRAB	0.82042E+09	-57.87	49.000	1.0000

```
          -----------------------------------------
          |                                       |
 MRA1     |                                       | MRA2
--------->|          81487.     LBMOL/HR          |--------->
   -29.00 |                                       |  -170.00
          |                                       |
 MRB1     |                                       | MRB2
--------->|          72221.     LBMOL/HR          |--------->
   -29.00 |                                       |  -170.00
          |                                       |
 NG4      |                                       | NG5
--------->|          81937.     LBMOL/HR          |--------->
   -29.00 |                                       |  -170.00
          |                                       |
 MR1      |                                       | MRAB
<---------|         0.15371E+06 LBMOL/HR          |<---------
   -57.87 |                                       |  -192.60
          |                                       |
          -----------------------------------------
```

*** INTERNAL ANALYSIS ***

FLOW IS COUNTERCURRENT.		
DUTY	0.82042E+09	BTU/HR
UA	0.64466E+08	BTU/HR-R
AVERAGE LMTD (DUTY/UA)	12.726	F
MIN TEMP APPROACH	6.2279	F
HOT-SIDE TEMP APPROACH	28.865	F
COLD-SIDE TEMP APPROACH	22.608	F
HOT-SIDE NTU	11.079	
COLD-SIDE NTU	10.587	

```
  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

   0.000       -170.00   -192.60     22.61
  0.8204E+07   -167.99   -190.69     22.70     22.65  0.3622E+06
0.8204E+07  0.3622E+06
```

0.1641E+08	-166.00	-188.74	22.74	22.72	0.3611E+06	0.8204E+07	0.7233E+06	
0.2461E+08	-164.02	-186.75	22.73	22.73	0.3609E+06	0.8204E+07	0.1084E+07	
0.3282E+08	-162.05	-184.73	22.68	22.70	0.3614E+06	0.8204E+07	0.1446E+07	
0.4102E+08	-160.09	-182.68	22.59	22.63	0.3625E+06	0.8204E+07	0.1808E+07	
0.4923E+08	-158.15	-180.61	22.46	22.52	0.3642E+06	0.8204E+07	0.2172E+07	
0.5743E+08	-156.22	-178.53	22.31	22.39	0.3665E+06	0.8204E+07	0.2539E+07	
0.6563E+08	-154.31	-176.43	22.13	22.22	0.3692E+06	0.8204E+07	0.2908E+07	
0.7384E+08	-152.40	-174.34	21.94	22.03	0.3723E+06	0.8204E+07	0.3280E+07	
0.7578E+08	-151.95	-173.85	21.89	21.92	0.8842E+05	0.1938E+07	0.3369E+07	BP MRB1
0.8204E+08	-150.80	-172.25	21.44	21.67	0.2892E+06	0.6266E+07	0.3658E+07	
0.9025E+08	-149.32	-170.17	20.84	21.14	0.3880E+06	0.8204E+07	0.4046E+07	
0.9845E+08	-147.85	-168.10	20.25	20.54	0.3994E+06	0.8204E+07	0.4445E+07	
0.1067E+09	-146.39	-166.04	19.66	19.95	0.4112E+06	0.8204E+07	0.4857E+07	
0.1149E+09	-144.93	-164.01	19.08	19.37	0.4236E+06	0.8204E+07	0.5280E+07	
0.1231E+09	-143.49	-162.01	18.52	18.80	0.4364E+06	0.8204E+07	0.5717E+07	
0.1313E+09	-142.06	-160.03	17.98	18.25	0.4496E+06	0.8204E+07	0.6166E+07	
0.1395E+09	-140.63	-158.09	17.46	17.72	0.4631E+06	0.8204E+07	0.6629E+07	
0.1477E+09	-139.22	-156.18	16.96	17.21	0.4768E+06	0.8204E+07	0.7106E+07	
0.1559E+09	-137.81	-154.30	16.49	16.72	0.4907E+06	0.8204E+07	0.7597E+07	
0.1641E+09	-136.42	-152.46	16.04	16.26	0.5046E+06	0.8204E+07	0.8101E+07	
0.1723E+09	-135.03	-150.65	15.62	15.83	0.5184E+06	0.8204E+07	0.8620E+07	
0.1805E+09	-133.65	-148.88	15.23	15.42	0.5320E+06	0.8204E+07	0.9152E+07	
0.1887E+09	-132.28	-147.15	14.86	15.04	0.5453E+06	0.8204E+07	0.9697E+07	
0.1969E+09	-130.92	-145.45	14.53	14.70	0.5583E+06	0.8204E+07	0.1026E+08	
0.2051E+09	-129.57	-143.79	14.22	14.38	0.5707E+06	0.8204E+07	0.1083E+08	
0.2133E+09	-128.22	-142.16	13.95	14.08	0.5825E+06	0.8204E+07	0.1141E+08	

0.2215E+09	-126.88	-140.57	13.70	13.82	0.5936E+06	0.8204E+07	0.1200E+08
0.2297E+09	-125.54	-139.01	13.47	13.58	0.6040E+06	0.8204E+07	0.1261E+08
0.2379E+09	-124.22	-137.49	13.27	13.37	0.6135E+06	0.8204E+07	0.1322E+08
0.2461E+09	-122.90	-136.00	13.10	13.19	0.6222E+06	0.8204E+07	0.1384E+08
0.2543E+09	-121.59	-134.53	12.94	13.02	0.6302E+06	0.8204E+07	0.1447E+08
0.2625E+09	-120.29	-133.10	12.81	12.87	0.6374E+06	0.8204E+07	0.1511E+08
0.2707E+09	-119.00	-131.69	12.69	12.75	0.6436E+06	0.8204E+07	0.1575E+08
0.2789E+09	-117.72	-130.31	12.59	12.64	0.6490E+06	0.8204E+07	0.1640E+08
0.2871E+09	-116.46	-128.96	12.50	12.55	0.6539E+06	0.8204E+07	0.1706E+08
0.2954E+09	-115.21	-127.63	12.43	12.47	0.6582E+06	0.8204E+07	0.1771E+08
0.3036E+09	-113.97	-126.33	12.35	12.39	0.6622E+06	0.8204E+07	0.1838E+08

DUTY	T HOT	T COLD	DELTA T	LMTD	UA ZONE	Q ZONE	UA	PINCH POINT	STREAM IN/OUT/DEW/BUBBLE POINT
BTU/HR	F	F	F	F	BTU/HR-R	BTU/HR	BTU/HR-R		
0.3118E+09	-112.76	-125.04	12.28	12.32	0.6661E+06	0.8204E+07	0.1904E+08		
0.3200E+09	-111.57	-123.78	12.21	12.24	0.6700E+06	0.8204E+07	0.1971E+08		
0.3282E+09	-110.41	-122.53	12.12	12.16	0.6744E+06	0.8204E+07	0.2039E+08		
0.3364E+09	-109.28	-121.31	12.02	12.07	0.6795E+06	0.8204E+07	0.2107E+08		
0.3446E+09	-108.20	-120.10	11.90	11.96	0.6858E+06	0.8204E+07	0.2175E+08		
0.3528E+09	-107.15	-118.91	11.75	11.83	0.6936E+06	0.8204E+07	0.2245E+08		
0.3610E+09	-106.17	-117.73	11.56	11.66	0.7037E+06	0.8204E+07	0.2315E+08		
0.3692E+09	-105.24	-116.56	11.32	11.44	0.7170E+06	0.8204E+07	0.2387E+08		
0.3736E+09	-104.77	-115.94	11.17	11.24	0.3957E+06	0.4450E+07	0.2426E+08		BP NG4
0.3774E+09	-104.58	-115.41	10.83	11.00	0.3414E+06	0.3755E+07	0.2460E+08		
0.3856E+09	-104.14	-114.27	10.13	10.48	0.7830E+06	0.8204E+07	0.2539E+08		

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  0.3938E+09   -103.66   -113.14      9.48      9.80  0.8369E+06
0.8204E+07  0.2622E+08
  0.4020E+09   -103.14   -112.02      8.88      9.18  0.8939E+06
0.8204E+07  0.2712E+08
  0.4102E+09   -102.57   -110.91      8.34      8.61  0.9531E+06
0.8204E+07  0.2807E+08
  0.4184E+09   -101.94   -109.80      7.86      8.10  0.1013E+07
0.8204E+07  0.2908E+08
  0.4266E+09   -101.27   -108.71      7.44      7.65  0.1073E+07
0.8204E+07  0.3016E+08
  0.4348E+09   -100.54   -107.61      7.08      7.26  0.1131E+07
0.8204E+07  0.3129E+08
  0.4430E+09    -99.75   -106.53      6.78      6.93  0.1184E+07
0.8204E+07  0.3247E+08
  0.4512E+09    -98.90   -105.45      6.55      6.66  0.1232E+07
0.8204E+07  0.3370E+08
  0.4594E+09    -98.00   -104.37      6.38      6.46  0.1270E+07
0.8204E+07  0.3497E+08
  0.4676E+09    -97.03   -103.30      6.27      6.32  0.1297E+07
0.8204E+07  0.3627E+08
  0.4758E+09    -96.00   -102.23      6.23      6.25  0.1313E+07
0.8204E+07  0.3758E+08  GBL
  0.4840E+09    -94.92   -101.17      6.25      6.24  0.1315E+07
0.8204E+07  0.3890E+08
  0.4923E+09    -93.79   -100.10      6.32      6.28  0.1306E+07
0.8204E+07  0.4020E+08
  0.5005E+09    -92.60    -99.04      6.44      6.38  0.1286E+07
0.8204E+07  0.4149E+08
  0.5087E+09    -91.37    -97.99      6.62      6.53  0.1256E+07
0.8204E+07  0.4275E+08
  0.5169E+09    -90.09    -96.93      6.84      6.73  0.1219E+07
0.8204E+07  0.4397E+08
  0.5237E+09    -89.00    -96.06      7.05      6.95  0.9790E+06
0.6801E+07  0.4494E+08         DP  NG4
  0.5251E+09    -88.76    -95.88      7.12      7.09  0.1980E+06
0.1403E+07  0.4514E+08
  0.5333E+09    -87.31    -94.83      7.52      7.32  0.1121E+07
0.8204E+07  0.4626E+08
  0.5415E+09    -85.83    -93.78      7.95      7.73  0.1061E+07
0.8204E+07  0.4733E+08
  0.5497E+09    -84.33    -92.74      8.41      8.18  0.1003E+07
0.8204E+07  0.4833E+08
  0.5579E+09    -82.79    -91.70      8.90      8.65  0.9480E+06
0.8204E+07  0.4928E+08
  0.5661E+09    -81.24    -90.66      9.42      9.16  0.8959E+06
0.8204E+07  0.5017E+08
  0.5743E+09    -79.67    -89.63      9.96      9.68  0.8472E+06
0.8204E+07  0.5102E+08
  0.5825E+09    -78.08    -88.60     10.52     10.23  0.8018E+06
0.8204E+07  0.5182E+08
  0.5907E+09    -76.48    -87.58     11.10     10.80  0.7595E+06
0.8204E+07  0.5258E+08
```

0.5989E+09	-74.86	-86.56	11.69	11.39	0.7202E+06	0.8204E+07	0.5330E+08
0.6071E+09	-73.24	-85.55	12.31	12.00	0.6837E+06	0.8204E+07	0.5399E+08
0.6153E+09	-71.60	-84.54	12.94	12.62	0.6499E+06	0.8204E+07	0.5463E+08
0.6235E+09	-69.95	-83.54	13.59	13.26	0.6185E+06	0.8204E+07	0.5525E+08
0.6317E+09	-68.29	-82.55	14.26	13.92	0.5893E+06	0.8204E+07	0.5584E+08
0.6399E+09	-66.63	-81.57	14.94	14.60	0.5621E+06	0.8204E+07	0.5640E+08
0.6481E+09	-64.96	-80.60	15.63	15.28	0.5368E+06	0.8204E+07	0.5694E+08
0.6563E+09	-63.29	-79.63	16.34	15.99	0.5132E+06	0.8204E+07	0.5745E+08
0.6645E+09	-61.60	-78.67	17.07	16.70	0.4911E+06	0.8204E+07	0.5795E+08
0.6727E+09	-59.92	-77.73	17.81	17.44	0.4705E+06	0.8204E+07	0.5842E+08
0.6810E+09	-58.23	-76.79	18.56	18.18	0.4512E+06	0.8204E+07	0.5887E+08
0.6892E+09	-56.53	-75.87	19.33	18.95	0.4330E+06	0.8204E+07	0.5930E+08
0.6974E+09	-54.84	-74.95	20.12	19.72	0.4160E+06	0.8204E+07	0.5972E+08

DUTY BTU/HR	T HOT F	T COLD F	DELTA T F	LMTD F	UA ZONE BTU/HR-R	Q ZONE BTU/HR	UA BTU/HR-R	PINCH	STREAM IN/OUT/DEW/ POINT BUBBLE POINT
0.7056E+09	-53.13	-74.05	20.91	20.51	0.4000E+06	0.8204E+07	0.6012E+08		
0.7138E+09	-51.43	-73.16	21.73	21.32	0.3848E+06	0.8204E+07	0.6050E+08		
0.7220E+09	-49.72	-72.28	22.56	22.14	0.3706E+06	0.8204E+07	0.6087E+08		
0.7302E+09	-48.01	-71.41	23.40	22.97	0.3571E+06	0.8204E+07	0.6123E+08		
0.7384E+09	-46.30	-70.55	24.25	23.82	0.3444E+06	0.8204E+07	0.6157E+08		
0.7466E+09	-44.58	-69.70	25.13	24.69	0.3323E+06	0.8204E+07	0.6191E+08		
0.7548E+09	-42.86	-68.87	26.01	25.57	0.3209E+06	0.8204E+07	0.6223E+08		
0.7630E+09	-41.13	-68.05	26.92	26.46	0.3100E+06	0.8204E+07	0.6254E+08		
0.7712E+09	-39.41	-67.24	27.83	27.37	0.2997E+06	0.8204E+07	0.6284E+08		

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  0.7794E+09    -37.68    -66.44     28.77     28.30  0.2899E+06
0.8204E+07  0.6313E+08
  0.7876E+09    -35.95    -65.66     29.71     29.24  0.2806E+06
0.8204E+07  0.6341E+08
  0.7958E+09    -34.21    -64.88     30.67     30.19  0.2718E+06
0.8204E+07  0.6368E+08
  0.8040E+09    -32.48    -64.12     31.65     31.16  0.2633E+06
0.8204E+07  0.6394E+08
  0.8116E+09    -30.86    -63.42     32.56     32.10  0.2372E+06
0.7616E+07  0.6418E+08         DP  MRAB
  0.8122E+09    -30.74    -63.05     32.31     32.44  0.1814E+05
0.5885E+06  0.6420E+08
  0.8204E+09    -29.00    -57.87     28.87     30.56  0.2685E+06
0.8204E+07  0.6447E+08


  GBL = GLOBAL     LOC = LOCAL     DP  = DEW POINT     BP  = BUBBLE
POINT

 BLOCK:  CHX2     MODEL: MHEATX
 ------------------------------

   HOT SIDE:    INLET STREAM     OUTLET STREAM
                ------------     -------------
                NG5              NG6
                MRB2             MRB3

   COLD SIDE:   INLET STREAM     OUTLET STREAM
                ------------     -------------
                MRB4             MRB5

   PROPERTIES FOR STREAM NG5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           226378.         226378.
0.00000
       MASS(LB/HR   )          0.450956E+07    0.450956E+07
0.00000
```

ENTHALPY(BTU/HR) -0.786400E+10 -0.786400E+10
0.00000

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.658719E+08	LB/HR
PRODUCT STREAMS CO2E	0.658719E+08	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 ***

SPECIFICATIONS FOR STREAM NG5 :
TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	F	-262.000
PRESSURE DROP	PSI	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

SPECIFICATIONS FOR STREAM MRB2 :
TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	F	-262.000
PRESSURE DROP	PSI	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

SPECIFICATIONS FOR STREAM MRB4 :
TWO PHASE FLASH

PRESSURE DROP	PSI	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

INLET STREAM	DUTY BTU/HR	OUTLET TEMPERATURE F	OUTLET PRESSURE PSIA	OUTLET VAPOR FRAC
NG5	-0.11313E+09	-262.00	720.00	0.0000
MRB2	-0.10277E+09	-262.00	600.00	0.0000
MRB4	0.21590E+09	-198.70	51.000	0.7265

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          ------------------------------------------
          |                                        |
NG5       |                                        | NG6
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 --------->|          81937.     LBMOL/HR          |--------->
   -170.00 |                                       |  -262.00
           |                                       |
  MRB2     |                                       | MRB3
 --------->|          72221.     LBMOL/HR          |--------->
   -170.00 |                                       |  -262.00
           |                                       |
  MRB5     |                                       | MRB4
 <---------|          72221.     LBMOL/HR          |<---------
   -198.70 |                                       |  -267.58
           |                                       |
           -----------------------------------------


                                ***  INTERNAL ANALYSIS  ***

  FLOW IS COUNTERCURRENT.
  DUTY                                0.21590E+09 BTU/HR
  UA                                  0.15527E+08 BTU/HR-R
  AVERAGE LMTD (DUTY/UA)               13.904     F
  MIN TEMP APPROACH                    5.5799     F
  HOT-SIDE TEMP APPROACH               28.704     F
  COLD-SIDE TEMP APPROACH              5.5799     F
  HOT-SIDE NTU                         6.6166
  COLD-SIDE NTU                        4.9535

  DUTY           T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F          F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

   0.000       -262.00   -267.58      5.58
GBL
  0.2159E+07   -261.02   -266.80      5.78      5.68  0.3801E+06
0.2159E+07  0.3801E+06
  0.4318E+07   -260.04   -266.00      5.97      5.87  0.3676E+06
0.2159E+07  0.7477E+06
  0.6477E+07   -259.06   -265.20      6.14      6.05  0.3567E+06
0.2159E+07  0.1104E+07
  0.8636E+07   -258.08   -264.38      6.30      6.22  0.3473E+06
0.2159E+07  0.1452E+07
  0.1079E+08   -257.10   -263.55      6.44      6.37  0.3389E+06
0.2159E+07  0.1791E+07
  0.1295E+08   -256.12   -262.70      6.58      6.51  0.3315E+06
0.2159E+07  0.2122E+07
  0.1511E+08   -255.15   -261.86      6.71      6.65  0.3249E+06
0.2159E+07  0.2447E+07
  0.1727E+08   -254.17   -261.00      6.83      6.77  0.3188E+06
0.2159E+07  0.2766E+07
```

0.1943E+08	-253.20	-260.15	6.95	6.89	0.3132E+06	0.2159E+07	0.3079E+07
0.2159E+08	-252.22	-259.29	7.07	7.01	0.3080E+06	0.2159E+07	0.3387E+07
0.2375E+08	-251.25	-258.43	7.18	7.12	0.3031E+06	0.2159E+07	0.3690E+07
0.2591E+08	-250.27	-257.57	7.29	7.24	0.2983E+06	0.2159E+07	0.3988E+07
0.2807E+08	-249.30	-256.71	7.41	7.35	0.2936E+06	0.2159E+07	0.4282E+07
0.3023E+08	-248.33	-255.86	7.53	7.47	0.2890E+06	0.2159E+07	0.4571E+07
0.3238E+08	-247.36	-255.02	7.66	7.59	0.2843E+06	0.2159E+07	0.4855E+07
0.3454E+08	-246.39	-254.18	7.79	7.72	0.2796E+06	0.2159E+07	0.5135E+07
0.3670E+08	-245.42	-253.35	7.93	7.86	0.2748E+06	0.2159E+07	0.5410E+07
0.3886E+08	-244.46	-252.53	8.07	8.00	0.2699E+06	0.2159E+07	0.5680E+07
0.4102E+08	-243.49	-251.72	8.23	8.15	0.2649E+06	0.2159E+07	0.5945E+07
0.4318E+08	-242.52	-250.92	8.40	8.31	0.2597E+06	0.2159E+07	0.6204E+07
0.4534E+08	-241.56	-250.14	8.58	8.49	0.2544E+06	0.2159E+07	0.6459E+07
0.4750E+08	-240.60	-249.36	8.77	8.67	0.2489E+06	0.2159E+07	0.6708E+07
0.4966E+08	-239.63	-248.61	8.97	8.87	0.2434E+06	0.2159E+07	0.6951E+07
0.5182E+08	-238.67	-247.86	9.19	9.08	0.2378E+06	0.2159E+07	0.7189E+07
0.5397E+08	-237.71	-247.13	9.42	9.30	0.2321E+06	0.2159E+07	0.7421E+07
0.5613E+08	-236.75	-246.41	9.66	9.54	0.2263E+06	0.2159E+07	0.7647E+07
0.5829E+08	-235.79	-245.71	9.92	9.79	0.2205E+06	0.2159E+07	0.7868E+07
0.6045E+08	-234.84	-245.03	10.19	10.05	0.2147E+06	0.2159E+07	0.8083E+07
0.6261E+08	-233.88	-244.35	10.47	10.33	0.2090E+06	0.2159E+07	0.8292E+07
0.6477E+08	-232.92	-243.69	10.77	10.62	0.2033E+06	0.2159E+07	0.8495E+07
0.6693E+08	-231.97	-243.05	11.08	10.92	0.1976E+06	0.2159E+07	0.8692E+07
0.6909E+08	-231.02	-242.42	11.40	11.24	0.1921E+06	0.2159E+07	0.8885E+07
0.7125E+08	-230.07	-241.80	11.74	11.57	0.1866E+06	0.2159E+07	0.9071E+07
0.7341E+08	-229.12	-241.20	12.08	11.91	0.1813E+06	0.2159E+07	0.9252E+07

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  0.7556E+08   -228.17   -240.61     12.44     12.26  0.1761E+06
0.2159E+07  0.9428E+07
  0.7772E+08   -227.22   -240.03     12.81     12.63  0.1710E+06
0.2159E+07  0.9599E+07
  0.7988E+08   -226.27   -239.47     13.19     13.00  0.1660E+06
0.2159E+07  0.9766E+07
  0.8204E+08   -225.33   -238.91     13.58     13.39  0.1613E+06
0.2159E+07  0.9927E+07

  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.8420E+08   -224.38   -238.37     13.98     13.78  0.1566E+06
0.2159E+07  0.1008E+08
  0.8636E+08   -223.44   -237.83     14.39     14.19  0.1522E+06
0.2159E+07  0.1024E+08
  0.8852E+08   -222.50   -237.31     14.81     14.60  0.1479E+06
0.2159E+07  0.1038E+08
  0.9068E+08   -221.56   -236.80     15.24     15.02  0.1437E+06
0.2159E+07  0.1053E+08
  0.9284E+08   -220.62   -236.29     15.67     15.45  0.1397E+06
0.2159E+07  0.1067E+08
  0.9499E+08   -219.68   -235.79     16.11     15.89  0.1359E+06
0.2159E+07  0.1080E+08
  0.9715E+08   -218.75   -235.30     16.56     16.33  0.1322E+06
0.2159E+07  0.1093E+08
  0.9931E+08   -217.81   -234.82     17.01     16.78  0.1286E+06
0.2159E+07  0.1106E+08
  0.1015E+09   -216.88   -234.35     17.47     17.24  0.1252E+06
0.2159E+07  0.1119E+08
  0.1036E+09   -215.95   -233.88     17.93     17.70  0.1220E+06
0.2159E+07  0.1131E+08
  0.1058E+09   -215.02   -233.41     18.40     18.16  0.1189E+06
0.2159E+07  0.1143E+08
  0.1079E+09   -214.09   -232.95     18.87     18.63  0.1159E+06
0.2159E+07  0.1155E+08
  0.1101E+09   -213.16   -232.50     19.34     19.10  0.1130E+06
0.2159E+07  0.1166E+08
  0.1123E+09   -212.23   -232.05     19.81     19.57  0.1103E+06
0.2159E+07  0.1177E+08
  0.1144E+09   -211.31   -231.60     20.29     20.05  0.1077E+06
0.2159E+07  0.1188E+08
  0.1166E+09   -210.39   -231.15     20.76     20.53  0.1052E+06
0.2159E+07  0.1198E+08
  0.1187E+09   -209.47   -230.71     21.24     21.00  0.1028E+06
0.2159E+07  0.1208E+08
  0.1209E+09   -208.55   -230.26     21.72     21.48  0.1005E+06
0.2159E+07  0.1219E+08
```

0.1231E+09	-207.63	-229.82	22.19	21.95	0.9835E+05	0.2159E+07	0.1228E+08
0.1252E+09	-206.71	-229.38	22.67	22.43	0.9627E+05	0.2159E+07	0.1238E+08
0.1274E+09	-205.80	-228.94	23.14	22.90	0.9428E+05	0.2159E+07	0.1247E+08
0.1295E+09	-204.89	-228.49	23.60	23.37	0.9238E+05	0.2159E+07	0.1257E+08
0.1317E+09	-203.97	-228.04	24.07	23.84	0.9057E+05	0.2159E+07	0.1266E+08
0.1339E+09	-203.07	-227.59	24.53	24.30	0.8885E+05	0.2159E+07	0.1275E+08
0.1360E+09	-202.16	-227.14	24.98	24.76	0.8721E+05	0.2159E+07	0.1283E+08
0.1382E+09	-201.25	-226.68	25.43	25.21	0.8565E+05	0.2159E+07	0.1292E+08
0.1403E+09	-200.35	-226.22	25.87	25.65	0.8416E+05	0.2159E+07	0.1300E+08
0.1425E+09	-199.45	-225.75	26.31	26.09	0.8275E+05	0.2159E+07	0.1309E+08
0.1447E+09	-198.54	-225.28	26.73	26.52	0.8141E+05	0.2159E+07	0.1317E+08
0.1468E+09	-197.65	-224.80	27.15	26.94	0.8014E+05	0.2159E+07	0.1325E+08
0.1490E+09	-196.75	-224.30	27.56	27.35	0.7893E+05	0.2159E+07	0.1333E+08
0.1511E+09	-195.85	-223.80	27.95	27.75	0.7780E+05	0.2159E+07	0.1340E+08
0.1533E+09	-194.96	-223.29	28.33	28.14	0.7672E+05	0.2159E+07	0.1348E+08
0.1554E+09	-194.07	-222.77	28.70	28.52	0.7571E+05	0.2159E+07	0.1356E+08
0.1576E+09	-193.18	-222.23	29.05	28.88	0.7477E+05	0.2159E+07	0.1363E+08
0.1598E+09	-192.29	-221.69	29.39	29.22	0.7388E+05	0.2159E+07	0.1370E+08
0.1619E+09	-191.41	-221.12	29.71	29.55	0.7306E+05	0.2159E+07	0.1378E+08
0.1641E+09	-190.53	-220.54	30.02	29.86	0.7229E+05	0.2159E+07	0.1385E+08
0.1662E+09	-189.64	-219.94	30.30	30.16	0.7159E+05	0.2159E+07	0.1392E+08
0.1684E+09	-188.77	-219.33	30.56	30.43	0.7095E+05	0.2159E+07	0.1399E+08
0.1706E+09	-187.89	-218.69	30.80	30.68	0.7037E+05	0.2159E+07	0.1406E+08
0.1727E+09	-187.01	-218.03	31.02	30.91	0.6985E+05	0.2159E+07	0.1413E+08
0.1749E+09	-186.14	-217.35	31.21	31.11	0.6939E+05	0.2159E+07	0.1420E+08
0.1770E+09	-185.27	-216.65	31.37	31.29	0.6899E+05	0.2159E+07	0.1427E+08

0.1792E+09	-184.40	-215.91	31.51	31.44	0.6866E+05	0.2159E+07	0.1434E+08
0.1814E+09	-183.54	-215.16	31.62	31.57	0.6840E+05	0.2159E+07	0.1441E+08
0.1835E+09	-182.67	-214.37	31.70	31.66	0.6820E+05	0.2159E+07	0.1448E+08
0.1857E+09	-181.81	-213.55	31.74	31.72	0.6806E+05	0.2159E+07	0.1454E+08
0.1878E+09	-180.95	-212.71	31.75	31.75	0.6800E+05	0.2159E+07	0.1461E+08
0.1900E+09	-180.09	-211.83	31.73	31.74	0.6801E+05	0.2159E+07	0.1468E+08

DUTY	T HOT	T COLD	DELTA T	LMTD	UA ZONE	Q ZONE	UA	PINCH POINT	STREAM IN/OUT/DEW/ BUBBLE POINT
BTU/HR	F	F	F	F	BTU/HR-R	BTU/HR	BTU/HR-R		
0.1921E+09	-179.24	-210.91	31.67	31.70	0.6810E+05	0.2159E+07	0.1475E+08		
0.1943E+09	-178.39	-209.97	31.58	31.63	0.6826E+05	0.2159E+07	0.1482E+08		
0.1965E+09	-177.54	-208.99	31.45	31.52	0.6850E+05	0.2159E+07	0.1489E+08		
0.1986E+09	-176.69	-207.97	31.28	31.37	0.6883E+05	0.2159E+07	0.1495E+08		
0.2008E+09	-175.84	-206.93	31.08	31.18	0.6924E+05	0.2159E+07	0.1502E+08		
0.2029E+09	-175.00	-205.84	30.84	30.96	0.6973E+05	0.2159E+07	0.1509E+08		
0.2051E+09	-174.16	-204.73	30.57	30.70	0.7032E+05	0.2159E+07	0.1516E+08		
0.2073E+09	-173.32	-203.58	30.26	30.41	0.7099E+05	0.2159E+07	0.1523E+08		
0.2094E+09	-172.49	-202.40	29.91	30.08	0.7176E+05	0.2159E+07	0.1531E+08		
0.2116E+09	-171.66	-201.20	29.54	29.73	0.7263E+05	0.2159E+07	0.1538E+08		
0.2137E+09	-170.83	-199.96	29.14	29.34	0.7359E+05	0.2159E+07	0.1545E+08		
0.2159E+09	-170.00	-198.70	28.70	28.92	0.7466E+05	0.2159E+07	0.1553E+08		

GBL = GLOBAL LOC = LOCAL DP = DEW POINT BP = BUBBLE POINT

BLOCK: CHX2 MODEL: MHEATX

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   HOT SIDE:     INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 NG5              NG6
                 MRB2             MRB3

   COLD SIDE:    INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 MRB4             MRB5

   PROPERTIES FOR STREAM NG5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN                OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            226378.         226378.
0.00000
       MASS(LB/HR   )          0.450956E+07    0.450956E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.786400E+10   -0.786400E+10
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.658719E+08  LB/HR
    PRODUCT STREAMS CO2E         0.658719E+08  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  ***


   SPECIFICATIONS FOR STREAM NG5     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               F                      -
262.000
   PRESSURE DROP                       PSI                       0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE
0.000100000
```

```
   SPECIFICATIONS FOR STREAM MRB2    :
   TWO    PHASE   TP  FLASH
   SPECIFIED TEMPERATURE              F                        -
262.000
   PRESSURE DROP                      PSI                        0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRB4    :
   TWO    PHASE      FLASH
   PRESSURE DROP                      PSI                        0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE
0.000100000
```

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                         ***  RESULTS  ***

  INLET                 OUTLET        OUTLET        OUTLET
  STREAM    DUTY        TEMPERATURE  PRESSURE      VAPOR FRAC
            BTU/HR      F             PSIA

  NG5       -0.11313E+09   -262.00      720.00        0.0000
  MRB2      -0.10277E+09   -262.00      600.00        0.0000
  MRB4       0.21590E+09   -198.70      51.000        0.7265


          -----------------------------------------
         |                                         |
  NG5    |                                         | NG6
 --------->|        81937.     LBMOL/HR            |--------->
   -170.00 |                                       |  -262.00
         |                                         |
  MRB2   |                                         | MRB3
 --------->|        72221.     LBMOL/HR            |--------->
   -170.00 |                                       |  -262.00
         |                                         |
  MRB5   |                                         | MRB4
 <---------|        72221.     LBMOL/HR            |<---------
   -198.70 |                                       |  -267.58
         |                                         |
          -----------------------------------------
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                         ***  INTERNAL ANALYSIS  ***

  FLOW IS COUNTERCURRENT.
  DUTY                              0.21590E+09 BTU/HR
  UA                                0.15527E+08 BTU/HR-R
  AVERAGE LMTD (DUTY/UA)             13.904     F
  MIN TEMP APPROACH                  5.5799     F
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HOT-SIDE TEMP APPROACH	28.704	F
COLD-SIDE TEMP APPROACH	5.5799	F
HOT-SIDE NTU	6.6166	
COLD-SIDE NTU	4.9535	

DUTY BTU/HR	T HOT F	T COLD F	DELTA T F	LMTD F	UA ZONE BTU/HR-R	Q ZONE BTU/HR	UA BTU/HR-R	PINCH POINT	STREAM IN/OUT/DEW/ BUBBLE POINT
0.000	-262.00	-267.58	5.58						GBL
0.2159E+07	-261.02	-266.80	5.78	5.68	0.3801E+06	0.2159E+07	0.3801E+06		
0.4318E+07	-260.04	-266.00	5.97	5.87	0.3676E+06	0.2159E+07	0.7477E+06		
0.6477E+07	-259.06	-265.20	6.14	6.05	0.3567E+06	0.2159E+07	0.1104E+07		
0.8636E+07	-258.08	-264.38	6.30	6.22	0.3473E+06	0.2159E+07	0.1452E+07		
0.1079E+08	-257.10	-263.55	6.44	6.37	0.3389E+06	0.2159E+07	0.1791E+07		
0.1295E+08	-256.12	-262.70	6.58	6.51	0.3315E+06	0.2159E+07	0.2122E+07		
0.1511E+08	-255.15	-261.86	6.71	6.65	0.3249E+06	0.2159E+07	0.2447E+07		
0.1727E+08	-254.17	-261.00	6.83	6.77	0.3188E+06	0.2159E+07	0.2766E+07		
0.1943E+08	-253.20	-260.15	6.95	6.89	0.3132E+06	0.2159E+07	0.3079E+07		
0.2159E+08	-252.22	-259.29	7.07	7.01	0.3080E+06	0.2159E+07	0.3387E+07		
0.2375E+08	-251.25	-258.43	7.18	7.12	0.3031E+06	0.2159E+07	0.3690E+07		
0.2591E+08	-250.27	-257.57	7.29	7.24	0.2983E+06	0.2159E+07	0.3988E+07		
0.2807E+08	-249.30	-256.71	7.41	7.35	0.2936E+06	0.2159E+07	0.4282E+07		
0.3023E+08	-248.33	-255.86	7.53	7.47	0.2890E+06	0.2159E+07	0.4571E+07		
0.3238E+08	-247.36	-255.02	7.66	7.59	0.2843E+06	0.2159E+07	0.4855E+07		
0.3454E+08	-246.39	-254.18	7.79	7.72	0.2796E+06	0.2159E+07	0.5135E+07		
0.3670E+08	-245.42	-253.35	7.93	7.86	0.2748E+06	0.2159E+07	0.5410E+07		
0.3886E+08	-244.46	-252.53	8.07	8.00	0.2699E+06	0.2159E+07	0.5680E+07		
0.4102E+08	-243.49	-251.72	8.23	8.15	0.2649E+06	0.2159E+07	0.5945E+07		

0.4318E+08	-242.52	-250.92	8.40	8.31	0.2597E+06	0.2159E+07	0.6204E+07
0.4534E+08	-241.56	-250.14	8.58	8.49	0.2544E+06	0.2159E+07	0.6459E+07
0.4750E+08	-240.60	-249.36	8.77	8.67	0.2489E+06	0.2159E+07	0.6708E+07
0.4966E+08	-239.63	-248.61	8.97	8.87	0.2434E+06	0.2159E+07	0.6951E+07
0.5182E+08	-238.67	-247.86	9.19	9.08	0.2378E+06	0.2159E+07	0.7189E+07
0.5397E+08	-237.71	-247.13	9.42	9.30	0.2321E+06	0.2159E+07	0.7421E+07
0.5613E+08	-236.75	-246.41	9.66	9.54	0.2263E+06	0.2159E+07	0.7647E+07
0.5829E+08	-235.79	-245.71	9.92	9.79	0.2205E+06	0.2159E+07	0.7868E+07
0.6045E+08	-234.84	-245.03	10.19	10.05	0.2147E+06	0.2159E+07	0.8083E+07
0.6261E+08	-233.88	-244.35	10.47	10.33	0.2090E+06	0.2159E+07	0.8292E+07
0.6477E+08	-232.92	-243.69	10.77	10.62	0.2033E+06	0.2159E+07	0.8495E+07
0.6693E+08	-231.97	-243.05	11.08	10.92	0.1976E+06	0.2159E+07	0.8692E+07
0.6909E+08	-231.02	-242.42	11.40	11.24	0.1921E+06	0.2159E+07	0.8885E+07
0.7125E+08	-230.07	-241.80	11.74	11.57	0.1866E+06	0.2159E+07	0.9071E+07
0.7341E+08	-229.12	-241.20	12.08	11.91	0.1813E+06	0.2159E+07	0.9252E+07
0.7556E+08	-228.17	-240.61	12.44	12.26	0.1761E+06	0.2159E+07	0.9428E+07
0.7772E+08	-227.22	-240.03	12.81	12.63	0.1710E+06	0.2159E+07	0.9599E+07
0.7988E+08	-226.27	-239.47	13.19	13.00	0.1660E+06	0.2159E+07	0.9766E+07
0.8204E+08	-225.33	-238.91	13.58	13.39	0.1613E+06	0.2159E+07	0.9927E+07

DUTY T HOT T COLD DELTA T LMTD UA ZONE Q ZONE UA PINCH STREAM IN/OUT/DEW/

POINT BUBBLE POINT

DUTY BTU/HR	T HOT F	T COLD F	DELTA T F	LMTD F	UA ZONE BTU/HR-R	Q ZONE BTU/HR	UA BTU/HR-R
0.8420E+08	-224.38	-238.37	13.98	13.78	0.1566E+06	0.2159E+07	0.1008E+08
0.8636E+08	-223.44	-237.83	14.39	14.19	0.1522E+06	0.2159E+07	0.1024E+08
0.8852E+08	-222.50	-237.31	14.81	14.60	0.1479E+06	0.2159E+07	0.1038E+08

0.9068E+08	-221.56	-236.80	15.24	15.02	0.1437E+06	0.2159E+07	0.1053E+08
0.9284E+08	-220.62	-236.29	15.67	15.45	0.1397E+06	0.2159E+07	0.1067E+08
0.9499E+08	-219.68	-235.79	16.11	15.89	0.1359E+06	0.2159E+07	0.1080E+08
0.9715E+08	-218.75	-235.30	16.56	16.33	0.1322E+06	0.2159E+07	0.1093E+08
0.9931E+08	-217.81	-234.82	17.01	16.78	0.1286E+06	0.2159E+07	0.1106E+08
0.1015E+09	-216.88	-234.35	17.47	17.24	0.1252E+06	0.2159E+07	0.1119E+08
0.1036E+09	-215.95	-233.88	17.93	17.70	0.1220E+06	0.2159E+07	0.1131E+08
0.1058E+09	-215.02	-233.41	18.40	18.16	0.1189E+06	0.2159E+07	0.1143E+08
0.1079E+09	-214.09	-232.95	18.87	18.63	0.1159E+06	0.2159E+07	0.1155E+08
0.1101E+09	-213.16	-232.50	19.34	19.10	0.1130E+06	0.2159E+07	0.1166E+08
0.1123E+09	-212.23	-232.05	19.81	19.57	0.1103E+06	0.2159E+07	0.1177E+08
0.1144E+09	-211.31	-231.60	20.29	20.05	0.1077E+06	0.2159E+07	0.1188E+08
0.1166E+09	-210.39	-231.15	20.76	20.53	0.1052E+06	0.2159E+07	0.1198E+08
0.1187E+09	-209.47	-230.71	21.24	21.00	0.1028E+06	0.2159E+07	0.1208E+08
0.1209E+09	-208.55	-230.26	21.72	21.48	0.1005E+06	0.2159E+07	0.1219E+08
0.1231E+09	-207.63	-229.82	22.19	21.95	0.9835E+05	0.2159E+07	0.1228E+08
0.1252E+09	-206.71	-229.38	22.67	22.43	0.9627E+05	0.2159E+07	0.1238E+08
0.1274E+09	-205.80	-228.94	23.14	22.90	0.9428E+05	0.2159E+07	0.1247E+08
0.1295E+09	-204.89	-228.49	23.60	23.37	0.9238E+05	0.2159E+07	0.1257E+08
0.1317E+09	-203.97	-228.04	24.07	23.84	0.9057E+05	0.2159E+07	0.1266E+08
0.1339E+09	-203.07	-227.59	24.53	24.30	0.8885E+05	0.2159E+07	0.1275E+08
0.1360E+09	-202.16	-227.14	24.98	24.76	0.8721E+05	0.2159E+07	0.1283E+08
0.1382E+09	-201.25	-226.68	25.43	25.21	0.8565E+05	0.2159E+07	0.1292E+08
0.1403E+09	-200.35	-226.22	25.87	25.65	0.8416E+05	0.2159E+07	0.1300E+08
0.1425E+09	-199.45	-225.75	26.31	26.09	0.8275E+05	0.2159E+07	0.1309E+08
0.1447E+09	-198.54	-225.28	26.73	26.52	0.8141E+05	0.2159E+07	0.1317E+08

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  0.1468E+09   -197.65   -224.80     27.15     26.94  0.8014E+05
0.2159E+07  0.1325E+08
  0.1490E+09   -196.75   -224.30     27.56     27.35  0.7893E+05
0.2159E+07  0.1333E+08
  0.1511E+09   -195.85   -223.80     27.95     27.75  0.7780E+05
0.2159E+07  0.1340E+08
  0.1533E+09   -194.96   -223.29     28.33     28.14  0.7672E+05
0.2159E+07  0.1348E+08
  0.1554E+09   -194.07   -222.77     28.70     28.52  0.7571E+05
0.2159E+07  0.1356E+08
  0.1576E+09   -193.18   -222.23     29.05     28.88  0.7477E+05
0.2159E+07  0.1363E+08
  0.1598E+09   -192.29   -221.69     29.39     29.22  0.7388E+05
0.2159E+07  0.1370E+08
  0.1619E+09   -191.41   -221.12     29.71     29.55  0.7306E+05
0.2159E+07  0.1378E+08
  0.1641E+09   -190.53   -220.54     30.02     29.86  0.7229E+05
0.2159E+07  0.1385E+08
  0.1662E+09   -189.64   -219.94     30.30     30.16  0.7159E+05
0.2159E+07  0.1392E+08
  0.1684E+09   -188.77   -219.33     30.56     30.43  0.7095E+05
0.2159E+07  0.1399E+08
  0.1706E+09   -187.89   -218.69     30.80     30.68  0.7037E+05
0.2159E+07  0.1406E+08
  0.1727E+09   -187.01   -218.03     31.02     30.91  0.6985E+05
0.2159E+07  0.1413E+08
  0.1749E+09   -186.14   -217.35     31.21     31.11  0.6939E+05
0.2159E+07  0.1420E+08
  0.1770E+09   -185.27   -216.65     31.37     31.29  0.6899E+05
0.2159E+07  0.1427E+08
  0.1792E+09   -184.40   -215.91     31.51     31.44  0.6866E+05
0.2159E+07  0.1434E+08
  0.1814E+09   -183.54   -215.16     31.62     31.57  0.6840E+05
0.2159E+07  0.1441E+08
  0.1835E+09   -182.67   -214.37     31.70     31.66  0.6820E+05
0.2159E+07  0.1448E+08
  0.1857E+09   -181.81   -213.55     31.74     31.72  0.6806E+05
0.2159E+07  0.1454E+08
  0.1878E+09   -180.95   -212.71     31.75     31.75  0.6800E+05
0.2159E+07  0.1461E+08
  0.1900E+09   -180.09   -211.83     31.73     31.74  0.6801E+05
0.2159E+07  0.1468E+08

  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.1921E+09   -179.24   -210.91     31.67     31.70  0.6810E+05
0.2159E+07  0.1475E+08
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  0.1943E+09   -178.39   -209.97     31.58     31.63  0.6826E+05
0.2159E+07  0.1482E+08
  0.1965E+09   -177.54   -208.99     31.45     31.52  0.6850E+05
0.2159E+07  0.1489E+08
  0.1986E+09   -176.69   -207.97     31.28     31.37  0.6883E+05
0.2159E+07  0.1495E+08
  0.2008E+09   -175.84   -206.93     31.08     31.18  0.6924E+05
0.2159E+07  0.1502E+08
  0.2029E+09   -175.00   -205.84     30.84     30.96  0.6973E+05
0.2159E+07  0.1509E+08
  0.2051E+09   -174.16   -204.73     30.57     30.70  0.7032E+05
0.2159E+07  0.1516E+08
  0.2073E+09   -173.32   -203.58     30.26     30.41  0.7099E+05
0.2159E+07  0.1523E+08
  0.2094E+09   -172.49   -202.40     29.91     30.08  0.7176E+05
0.2159E+07  0.1531E+08
  0.2116E+09   -171.66   -201.20     29.54     29.73  0.7263E+05
0.2159E+07  0.1538E+08
  0.2137E+09   -170.83   -199.96     29.14     29.34  0.7359E+05
0.2159E+07  0.1545E+08
  0.2159E+09   -170.00   -198.70     28.70     28.92  0.7466E+05
0.2159E+07  0.1553E+08


  GBL = GLOBAL     LOC = LOCAL     DP  = DEW POINT     BP  = BUBBLE
POINT

 BLOCK:  CHX2     MODEL: MHEATX
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   HOT SIDE:    INLET STREAM     OUTLET STREAM
                ------------     -------------
                NG5              NG6
                MRB2             MRB3

   COLD SIDE:   INLET STREAM     OUTLET STREAM
                ------------     -------------
                MRB4             MRB5

   PROPERTIES FOR STREAM NG5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

   PROPERTIES FOR STREAM MRB4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
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                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           226378.         226378.
0.00000
       MASS(LB/HR   )          0.450956E+07    0.450956E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.786400E+10   -0.786400E+10
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.658719E+08  LB/HR
    PRODUCT STREAMS CO2E        0.658719E+08  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  ***


   SPECIFICATIONS FOR STREAM NG5     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                      -
262.000
   PRESSURE DROP                      PSI                      0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRB2    :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              F                      -
262.000
   PRESSURE DROP                      PSI                      0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE
0.000100000

   SPECIFICATIONS FOR STREAM MRB4    :
   TWO    PHASE      FLASH
   PRESSURE DROP                      PSI                      0.0
   MAXIMUM NO. ITERATIONS                                     30
   CONVERGENCE TOLERANCE
0.000100000

                          ***  RESULTS  ***

  INLET                  OUTLET       OUTLET       OUTLET
  STREAM    DUTY         TEMPERATURE  PRESSURE     VAPOR FRAC
            BTU/HR       F            PSIA
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  NG5       -0.11313E+09   -262.00      720.00         0.0000
  MRB2      -0.10277E+09   -262.00      600.00         0.0000
  MRB4       0.21590E+09   -198.70      51.000         0.7265


          ------------------------------------------
          |                                        |
  NG5     |                                        | NG6
 --------->|         81937.     LBMOL/HR           |---------->
   -170.00 |                                       |  -262.00
          |                                        |
  MRB2    |                                        | MRB3
 --------->|         72221.     LBMOL/HR           |---------->
   -170.00 |                                       |  -262.00
          |                                        |
  MRB5    |                                        | MRB4
 <---------|         72221.     LBMOL/HR           |<----------
   -198.70 |                                       |  -267.58
          |                                        |
          ------------------------------------------


                         ***  INTERNAL ANALYSIS  ***

  FLOW IS COUNTERCURRENT.
  DUTY                               0.21590E+09 BTU/HR
  UA                                 0.15527E+08 BTU/HR-R
  AVERAGE LMTD (DUTY/UA)              13.904     F
  MIN TEMP APPROACH                   5.5799     F
  HOT-SIDE TEMP APPROACH              28.704     F
  COLD-SIDE TEMP APPROACH             5.5799     F
  HOT-SIDE NTU                        6.6166
  COLD-SIDE NTU                       4.9535

  DUTY           T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

   0.000       -262.00   -267.58      5.58
GBL
  0.2159E+07   -261.02   -266.80      5.78      5.68  0.3801E+06
0.2159E+07  0.3801E+06
  0.4318E+07   -260.04   -266.00      5.97      5.87  0.3676E+06
0.2159E+07  0.7477E+06
  0.6477E+07   -259.06   -265.20      6.14      6.05  0.3567E+06
0.2159E+07  0.1104E+07
  0.8636E+07   -258.08   -264.38      6.30      6.22  0.3473E+06
0.2159E+07  0.1452E+07
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0.1079E+08	-257.10	-263.55	6.44	6.37	0.3389E+06	0.2159E+07	0.1791E+07
0.1295E+08	-256.12	-262.70	6.58	6.51	0.3315E+06	0.2159E+07	0.2122E+07
0.1511E+08	-255.15	-261.86	6.71	6.65	0.3249E+06	0.2159E+07	0.2447E+07
0.1727E+08	-254.17	-261.00	6.83	6.77	0.3188E+06	0.2159E+07	0.2766E+07
0.1943E+08	-253.20	-260.15	6.95	6.89	0.3132E+06	0.2159E+07	0.3079E+07
0.2159E+08	-252.22	-259.29	7.07	7.01	0.3080E+06	0.2159E+07	0.3387E+07
0.2375E+08	-251.25	-258.43	7.18	7.12	0.3031E+06	0.2159E+07	0.3690E+07
0.2591E+08	-250.27	-257.57	7.29	7.24	0.2983E+06	0.2159E+07	0.3988E+07
0.2807E+08	-249.30	-256.71	7.41	7.35	0.2936E+06	0.2159E+07	0.4282E+07
0.3023E+08	-248.33	-255.86	7.53	7.47	0.2890E+06	0.2159E+07	0.4571E+07
0.3238E+08	-247.36	-255.02	7.66	7.59	0.2843E+06	0.2159E+07	0.4855E+07
0.3454E+08	-246.39	-254.18	7.79	7.72	0.2796E+06	0.2159E+07	0.5135E+07
0.3670E+08	-245.42	-253.35	7.93	7.86	0.2748E+06	0.2159E+07	0.5410E+07
0.3886E+08	-244.46	-252.53	8.07	8.00	0.2699E+06	0.2159E+07	0.5680E+07
0.4102E+08	-243.49	-251.72	8.23	8.15	0.2649E+06	0.2159E+07	0.5945E+07
0.4318E+08	-242.52	-250.92	8.40	8.31	0.2597E+06	0.2159E+07	0.6204E+07
0.4534E+08	-241.56	-250.14	8.58	8.49	0.2544E+06	0.2159E+07	0.6459E+07
0.4750E+08	-240.60	-249.36	8.77	8.67	0.2489E+06	0.2159E+07	0.6708E+07
0.4966E+08	-239.63	-248.61	8.97	8.87	0.2434E+06	0.2159E+07	0.6951E+07
0.5182E+08	-238.67	-247.86	9.19	9.08	0.2378E+06	0.2159E+07	0.7189E+07
0.5397E+08	-237.71	-247.13	9.42	9.30	0.2321E+06	0.2159E+07	0.7421E+07
0.5613E+08	-236.75	-246.41	9.66	9.54	0.2263E+06	0.2159E+07	0.7647E+07
0.5829E+08	-235.79	-245.71	9.92	9.79	0.2205E+06	0.2159E+07	0.7868E+07
0.6045E+08	-234.84	-245.03	10.19	10.05	0.2147E+06	0.2159E+07	0.8083E+07
0.6261E+08	-233.88	-244.35	10.47	10.33	0.2090E+06	0.2159E+07	0.8292E+07
0.6477E+08	-232.92	-243.69	10.77	10.62	0.2033E+06	0.2159E+07	0.8495E+07

0.6693E+08	-231.97	-243.05	11.08	10.92	0.1976E+06	0.2159E+07	0.8692E+07		
0.6909E+08	-231.02	-242.42	11.40	11.24	0.1921E+06	0.2159E+07	0.8885E+07		
0.7125E+08	-230.07	-241.80	11.74	11.57	0.1866E+06	0.2159E+07	0.9071E+07		
0.7341E+08	-229.12	-241.20	12.08	11.91	0.1813E+06	0.2159E+07	0.9252E+07		
0.7556E+08	-228.17	-240.61	12.44	12.26	0.1761E+06	0.2159E+07	0.9428E+07		
0.7772E+08	-227.22	-240.03	12.81	12.63	0.1710E+06	0.2159E+07	0.9599E+07		
0.7988E+08	-226.27	-239.47	13.19	13.00	0.1660E+06	0.2159E+07	0.9766E+07		
0.8204E+08	-225.33	-238.91	13.58	13.39	0.1613E+06	0.2159E+07	0.9927E+07		

DUTY	T HOT	T COLD	DELTA T	LMTD	UA ZONE	Q ZONE	UA	PINCH POINT	STREAM IN/OUT/DEW/ BUBBLE POINT
BTU/HR	F	F	F	F	BTU/HR-R	BTU/HR	BTU/HR-R		
0.8420E+08	-224.38	-238.37	13.98	13.78	0.1566E+06	0.2159E+07	0.1008E+08		
0.8636E+08	-223.44	-237.83	14.39	14.19	0.1522E+06	0.2159E+07	0.1024E+08		
0.8852E+08	-222.50	-237.31	14.81	14.60	0.1479E+06	0.2159E+07	0.1038E+08		
0.9068E+08	-221.56	-236.80	15.24	15.02	0.1437E+06	0.2159E+07	0.1053E+08		
0.9284E+08	-220.62	-236.29	15.67	15.45	0.1397E+06	0.2159E+07	0.1067E+08		
0.9499E+08	-219.68	-235.79	16.11	15.89	0.1359E+06	0.2159E+07	0.1080E+08		
0.9715E+08	-218.75	-235.30	16.56	16.33	0.1322E+06	0.2159E+07	0.1093E+08		
0.9931E+08	-217.81	-234.82	17.01	16.78	0.1286E+06	0.2159E+07	0.1106E+08		
0.1015E+09	-216.88	-234.35	17.47	17.24	0.1252E+06	0.2159E+07	0.1119E+08		
0.1036E+09	-215.95	-233.88	17.93	17.70	0.1220E+06	0.2159E+07	0.1131E+08		
0.1058E+09	-215.02	-233.41	18.40	18.16	0.1189E+06	0.2159E+07	0.1143E+08		
0.1079E+09	-214.09	-232.95	18.87	18.63	0.1159E+06	0.2159E+07	0.1155E+08		
0.1101E+09	-213.16	-232.50	19.34	19.10	0.1130E+06	0.2159E+07	0.1166E+08		
0.1123E+09	-212.23	-232.05	19.81	19.57	0.1103E+06	0.2159E+07	0.1177E+08		

0.1144E+09	-211.31	-231.60	20.29	20.05	0.1077E+06	0.2159E+07	0.1188E+08
0.1166E+09	-210.39	-231.15	20.76	20.53	0.1052E+06	0.2159E+07	0.1198E+08
0.1187E+09	-209.47	-230.71	21.24	21.00	0.1028E+06	0.2159E+07	0.1208E+08
0.1209E+09	-208.55	-230.26	21.72	21.48	0.1005E+06	0.2159E+07	0.1219E+08
0.1231E+09	-207.63	-229.82	22.19	21.95	0.9835E+05	0.2159E+07	0.1228E+08
0.1252E+09	-206.71	-229.38	22.67	22.43	0.9627E+05	0.2159E+07	0.1238E+08
0.1274E+09	-205.80	-228.94	23.14	22.90	0.9428E+05	0.2159E+07	0.1247E+08
0.1295E+09	-204.89	-228.49	23.60	23.37	0.9238E+05	0.2159E+07	0.1257E+08
0.1317E+09	-203.97	-228.04	24.07	23.84	0.9057E+05	0.2159E+07	0.1266E+08
0.1339E+09	-203.07	-227.59	24.53	24.30	0.8885E+05	0.2159E+07	0.1275E+08
0.1360E+09	-202.16	-227.14	24.98	24.76	0.8721E+05	0.2159E+07	0.1283E+08
0.1382E+09	-201.25	-226.68	25.43	25.21	0.8565E+05	0.2159E+07	0.1292E+08
0.1403E+09	-200.35	-226.22	25.87	25.65	0.8416E+05	0.2159E+07	0.1300E+08
0.1425E+09	-199.45	-225.75	26.31	26.09	0.8275E+05	0.2159E+07	0.1309E+08
0.1447E+09	-198.54	-225.28	26.73	26.52	0.8141E+05	0.2159E+07	0.1317E+08
0.1468E+09	-197.65	-224.80	27.15	26.94	0.8014E+05	0.2159E+07	0.1325E+08
0.1490E+09	-196.75	-224.30	27.56	27.35	0.7893E+05	0.2159E+07	0.1333E+08
0.1511E+09	-195.85	-223.80	27.95	27.75	0.7780E+05	0.2159E+07	0.1340E+08
0.1533E+09	-194.96	-223.29	28.33	28.14	0.7672E+05	0.2159E+07	0.1348E+08
0.1554E+09	-194.07	-222.77	28.70	28.52	0.7571E+05	0.2159E+07	0.1356E+08
0.1576E+09	-193.18	-222.23	29.05	28.88	0.7477E+05	0.2159E+07	0.1363E+08
0.1598E+09	-192.29	-221.69	29.39	29.22	0.7388E+05	0.2159E+07	0.1370E+08
0.1619E+09	-191.41	-221.12	29.71	29.55	0.7306E+05	0.2159E+07	0.1378E+08
0.1641E+09	-190.53	-220.54	30.02	29.86	0.7229E+05	0.2159E+07	0.1385E+08
0.1662E+09	-189.64	-219.94	30.30	30.16	0.7159E+05	0.2159E+07	0.1392E+08
0.1684E+09	-188.77	-219.33	30.56	30.43	0.7095E+05	0.2159E+07	0.1399E+08

```
  0.1706E+09   -187.89   -218.69     30.80     30.68  0.7037E+05
0.2159E+07  0.1406E+08
  0.1727E+09   -187.01   -218.03     31.02     30.91  0.6985E+05
0.2159E+07  0.1413E+08
  0.1749E+09   -186.14   -217.35     31.21     31.11  0.6939E+05
0.2159E+07  0.1420E+08
  0.1770E+09   -185.27   -216.65     31.37     31.29  0.6899E+05
0.2159E+07  0.1427E+08
  0.1792E+09   -184.40   -215.91     31.51     31.44  0.6866E+05
0.2159E+07  0.1434E+08
  0.1814E+09   -183.54   -215.16     31.62     31.57  0.6840E+05
0.2159E+07  0.1441E+08
  0.1835E+09   -182.67   -214.37     31.70     31.66  0.6820E+05
0.2159E+07  0.1448E+08
  0.1857E+09   -181.81   -213.55     31.74     31.72  0.6806E+05
0.2159E+07  0.1454E+08
  0.1878E+09   -180.95   -212.71     31.75     31.75  0.6800E+05
0.2159E+07  0.1461E+08
  0.1900E+09   -180.09   -211.83     31.73     31.74  0.6801E+05
0.2159E+07  0.1468E+08

  DUTY          T HOT     T COLD    DELTA T   LMTD    UA ZONE     Q
ZONE      UA          PINCH  STREAM IN/OUT/DEW/

POINT  BUBBLE POINT
  BTU/HR          F         F         F         F     BTU/HR-R
BTU/HR      BTU/HR-R

  0.1921E+09   -179.24   -210.91     31.67     31.70  0.6810E+05
0.2159E+07  0.1475E+08
  0.1943E+09   -178.39   -209.97     31.58     31.63  0.6826E+05
0.2159E+07  0.1482E+08
  0.1965E+09   -177.54   -208.99     31.45     31.52  0.6850E+05
0.2159E+07  0.1489E+08
  0.1986E+09   -176.69   -207.97     31.28     31.37  0.6883E+05
0.2159E+07  0.1495E+08
  0.2008E+09   -175.84   -206.93     31.08     31.18  0.6924E+05
0.2159E+07  0.1502E+08
  0.2029E+09   -175.00   -205.84     30.84     30.96  0.6973E+05
0.2159E+07  0.1509E+08
  0.2051E+09   -174.16   -204.73     30.57     30.70  0.7032E+05
0.2159E+07  0.1516E+08
  0.2073E+09   -173.32   -203.58     30.26     30.41  0.7099E+05
0.2159E+07  0.1523E+08
  0.2094E+09   -172.49   -202.40     29.91     30.08  0.7176E+05
0.2159E+07  0.1531E+08
  0.2116E+09   -171.66   -201.20     29.54     29.73  0.7263E+05
0.2159E+07  0.1538E+08
  0.2137E+09   -170.83   -199.96     29.14     29.34  0.7359E+05
0.2159E+07  0.1545E+08
  0.2159E+09   -170.00   -198.70     28.70     28.92  0.7466E+05
0.2159E+07  0.1553E+08
```

```
  GBL = GLOBAL     LOC = LOCAL     DP  = DEW POINT     BP  = BUBBLE
POINT

 BLOCK:  C2       MODEL: COMPR
 -----------------------------
   INLET STREAM:          P26
   OUTLET STREAM:         P27
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           29725.2         29725.2
0.00000
       MASS(LB/HR   )          0.131078E+07    0.131078E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.140883E+10   -0.136242E+10   -
0.329422E-01

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

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  PSIA                                   18.0000
    ISENTROPIC EFFICIENCY                                    0.81000
    MECHANICAL EFFICIENCY                                    1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP               18,239.7
    BRAKE      HORSEPOWER REQUIREMENT  HP               18,239.7
    NET WORK REQUIRED                  HP               18,239.7
    POWER LOSSES                       HP                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP               14,774.2
    CALCULATED OUTLET TEMP  F                               32.4193
    ISENTROPIC TEMPERATURE  F                               14.6046
    EFFICIENCY (POLYTR/ISENTR) USED                          0.81000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       FT-LBF/LB                     22,317.2
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.15829
```

```
    INLET VOLUMETRIC FLOW RATE , CUFT/HR
0.307610+08
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR            8,504,740.
    INLET  COMPRESSIBILITY FACTOR                           0.98981
    OUTLET COMPRESSIBILITY FACTOR                           0.97523
    AV. ISENT. VOL. EXPONENT                                1.13489
    AV. ISENT. TEMP EXPONENT                                1.15020
    AV. ACTUAL VOL. EXPONENT                                1.16992
    AV. ACTUAL TEMP EXPONENT                                1.18358

 BLOCK:  C3       MODEL: COMPR
 -----------------------------
   INLET STREAMS:         P13         P23         P27
   OUTLET STREAM:         P14
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           49958.4         49958.4
0.00000
       MASS(LB/HR   )          0.220299E+07    0.220299E+07   -
0.211377E-15
       ENTHALPY(BTU/HR  )      -0.230709E+10   -0.223432E+10   -
0.315395E-01

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

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  PSIA                                  61.0000
    ISENTROPIC EFFICIENCY                                   0.81000
    MECHANICAL EFFICIENCY                                   1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP               28,597.5
    BRAKE      HORSEPOWER REQUIREMENT  HP               28,597.5
    NET WORK REQUIRED                  HP               28,597.5
    POWER LOSSES                       HP                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP               23,164.0
    CALCULATED OUTLET TEMP  F                             103.419
    ISENTROPIC TEMPERATURE  F                              88.5831
    EFFICIENCY (POLYTR/ISENTR) USED                         0.81000
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    OUTLET VAPOR FRACTION                                         1.00000
    HEAD DEVELOPED,       FT-LBF/LB                            20,819.3
    MECHANICAL EFFICIENCY USED                                    1.00000
    INLET HEAT CAPACITY RATIO                                     1.15411
    INLET VOLUMETRIC FLOW RATE , CUFT/HR
0.136429+08
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR            4,658,680.
    INLET  COMPRESSIBILITY FACTOR                                 0.97200
    OUTLET COMPRESSIBILITY FACTOR                                 0.94135
    AV. ISENT. VOL. EXPONENT                                      1.10296
    AV. ISENT. TEMP EXPONENT                                      1.14157
    AV. ACTUAL VOL. EXPONENT                                      1.13589
    AV. ACTUAL TEMP EXPONENT                                      1.17081

 BLOCK:  C4       MODEL: COMPR
 -----------------------------
   INLET STREAMS:         P10         P14         P19
   OUTLET STREAM:         P15
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           71369.1         71369.1
0.00000
       MASS(LB/HR   )          0.314713E+07    0.314713E+07
0.147964E-15
       ENTHALPY(BTU/HR  )      -0.322219E+10   -0.316507E+10   -
0.177282E-01

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

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  PSIA                                       115.000
    ISENTROPIC EFFICIENCY                                         0.81000
    MECHANICAL EFFICIENCY                                         1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP                22,450.4
    BRAKE      HORSEPOWER REQUIREMENT  HP                22,450.4
    NET WORK REQUIRED                  HP                22,450.4
    POWER LOSSES                       HP                     0.0
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    ISENTROPIC HORSEPOWER REQUIREMENT  HP              18,184.9
    CALCULATED OUTLET TEMP  F                             132.037
    ISENTROPIC TEMPERATURE  F                             124.429
    EFFICIENCY (POLYTR/ISENTR) USED                         0.81000
    OUTLET VAPOR FRACTION                                   1.00000
    HEAD DEVELOPED,       FT-LBF/LB                    11,440.9
    MECHANICAL EFFICIENCY USED                              1.00000
    INLET HEAT CAPACITY RATIO                               1.16285
    INLET VOLUMETRIC FLOW RATE , CUFT/HR               6,330,670.
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR               3,552,930.
    INLET  COMPRESSIBILITY FACTOR                           0.93333
    OUTLET COMPRESSIBILITY FACTOR                           0.90159
    AV. ISENT. VOL. EXPONENT                                1.06497
    AV. ISENT. TEMP EXPONENT                                1.14044
    AV. ACTUAL VOL. EXPONENT                                1.09768
    AV. ACTUAL TEMP EXPONENT                                1.16762

 BLOCK:  C5       MODEL: COMPR
 -----------------------------
   INLET STREAMS:         P5          P15
   OUTLET STREAM:         P1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           142738.         142738.
0.00000
       MASS(LB/HR   )          0.629426E+07    0.629426E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.642493E+10   -0.632913E+10   -
0.149097E-01

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

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  PSIA                                 200.000
    ISENTROPIC EFFICIENCY                                   0.81000
    MECHANICAL EFFICIENCY                                   1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP              37,648.4
```

BRAKE HORSEPOWER REQUIREMENT	HP	37,648.4
NET WORK REQUIRED	HP	37,648.4
POWER LOSSES	HP	0.0
ISENTROPIC HORSEPOWER REQUIREMENT	HP	30,495.2
CALCULATED OUTLET TEMP	F	146.792
ISENTROPIC TEMPERATURE	F	140.898
EFFICIENCY (POLYTR/ISENTR) USED		0.81000
OUTLET VAPOR FRACTION		1.00000
HEAD DEVELOPED,	FT-LBF/LB	9,592.95
MECHANICAL EFFICIENCY USED		1.00000
INLET HEAT CAPACITY RATIO		1.19713
INLET VOLUMETRIC FLOW RATE , CUFT/HR		6,545,190.
OUTLET VOLUMETRIC FLOW RATE, CUFT/HR		3,863,920.
INLET COMPRESSIBILITY FACTOR		0.88048
OUTLET COMPRESSIBILITY FACTOR		0.83188
AV. ISENT. VOL. EXPONENT		1.01669
AV. ISENT. TEMP EXPONENT		1.15282
AV. ACTUAL VOL. EXPONENT		1.04997
AV. ACTUAL TEMP EXPONENT		1.17676

BLOCK: C6 MODEL: COMPR

INLET STREAM: MR1
OUTLET STREAM: MR2
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	153708.	153708.	0.00000
MASS(LB/HR)	0.401628E+07	0.401628E+07	0.00000
ENTHALPY(BTU/HR)	-0.510703E+10	-0.476214E+10	-0.675332E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.252673E+08	LB/HR
PRODUCT STREAMS CO2E	0.252673E+08	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

OUTLET PRESSURE PSIA	350.000
ISENTROPIC EFFICIENCY	0.81000
MECHANICAL EFFICIENCY	1.00000

```
                          ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP              135,549.
    BRAKE      HORSEPOWER REQUIREMENT  HP              135,549.
    NET WORK REQUIRED                  HP              135,549.
    POWER LOSSES                       HP                  0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP              109,794.
    CALCULATED OUTLET TEMP  F                              167.806
    ISENTROPIC TEMPERATURE  F                              134.658
    EFFICIENCY (POLYTR/ISENTR) USED                          0.81000
    OUTLET VAPOR FRACTION                                    1.00000
    HEAD DEVELOPED,       FT-LBF/LB                     54,127.9
    MECHANICAL EFFICIENCY USED                               1.00000
    INLET HEAT CAPACITY RATIO                                1.28440
    INLET VOLUMETRIC FLOW RATE , CUFT/HR
0.130294+08
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR             2,776,880.
    INLET  COMPRESSIBILITY FACTOR                            0.96328
    OUTLET COMPRESSIBILITY FACTOR                            0.93902
    AV. ISENT. VOL. EXPONENT                                 1.21694
    AV. ISENT. TEMP EXPONENT                                 1.24860
    AV. ACTUAL VOL. EXPONENT                                 1.27184
    AV. ACTUAL TEMP EXPONENT                                 1.29318

 BLOCK:  C7       MODEL: COMPR
 -----------------------------
   INLET STREAM:          MR3
   OUTLET STREAM:         MR4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           153708.         153708.
0.00000
       MASS(LB/HR   )          0.401628E+07    0.401628E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.479678E+10   -0.466680E+10   -
0.270965E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E        0.252673E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
    UTILITIES CO2E PRODUCTION     0.00000     LB/HR
    TOTAL CO2E PRODUCTION         0.00000     LB/HR

                          ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
```

```
   OUTLET PRESSURE  PSIA                                         615.000
   ISENTROPIC EFFICIENCY                                           0.81000
   MECHANICAL EFFICIENCY                                           1.00000

                         ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP                      51,082.4
   BRAKE      HORSEPOWER REQUIREMENT  HP                      51,082.4
   NET WORK REQUIRED                  HP                      51,082.4
   POWER LOSSES                       HP                           0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP                      41,376.7
   CALCULATED OUTLET TEMP  F                                     228.810
   ISENTROPIC TEMPERATURE  F                                     217.434
   EFFICIENCY (POLYTR/ISENTR) USED                                 0.81000
   OUTLET VAPOR FRACTION                                           1.00000
   HEAD DEVELOPED,       FT-LBF/LB                            20,398.4
   MECHANICAL EFFICIENCY USED                                      1.00000
   INLET HEAT CAPACITY RATIO                                       1.28433
   INLET VOLUMETRIC FLOW RATE , CUFT/HR                    2,718,650.
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                    1,716,630.
   INLET  COMPRESSIBILITY FACTOR                                   0.93266
   OUTLET COMPRESSIBILITY FACTOR                                   0.92962
   AV. ISENT. VOL. EXPONENT                                        1.19846
   AV. ISENT. TEMP EXPONENT                                        1.22171
   AV. ACTUAL VOL. EXPONENT                                        1.25731
   AV. ACTUAL TEMP EXPONENT                                        1.26630

 BLOCK:  F1       MODEL: FLASH2
 ------------------------------
   INLET STREAM:          P4
   OUTLET VAPOR STREAM:   P5
   OUTLET LIQUID STREAM:  P6
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           142738.         142738.
0.00000
      MASS(LB/HR   )          0.629426E+07    0.629426E+07
0.00000
      ENTHALPY(BTU/HR  )      -0.728779E+10   -0.699870E+10   -
0.396683E-01

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

```
                         ***  INPUT DATA  ***
   TWO    PHASE  PV  FLASH
   SPECIFIED PRESSURE    PSIA                             115.000
   VAPOR FRACTION                                           0.50000
   MAXIMUM NO. ITERATIONS                                 30
   CONVERGENCE TOLERANCE
0.000100000

                          ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                  63.880
   OUTLET PRESSURE       PSIA                               115.00
   HEAT DUTY             BTU/HR
0.28909E+09
   VAPOR FRACTION                                           0.50000



   V-L PHASE EQUILIBRIUM :

      COMP            F(I)          X(I)          Y(I)
K(I)
      PROPA-01        1.0000        1.0000        1.0000
1.0000

 BLOCK:  F2       MODEL: FLASH2
 ------------------------------
   INLET STREAM:          P9
   OUTLET VAPOR STREAM:   P10
   OUTLET LIQUID STREAM:  P11
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                        IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           10705.4        10705.4
0.00000
       MASS(LB/HR   )           472069.        472069.
0.123303E-15
       ENTHALPY(BTU/HR  )      -0.526790E+09   -0.548984E+09
0.404291E-01

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

                         ***  INPUT DATA  ***
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   TWO    PHASE  PV  FLASH
   SPECIFIED PRESSURE    PSIA                              61.0000
   VAPOR FRACTION                                           0.30000
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE
0.000100000

                           ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                  24.969
   OUTLET PRESSURE       PSIA                               61.000
   HEAT DUTY             BTU/HR                            -
0.22195E+08
   VAPOR FRACTION                                           0.30000



   V-L PHASE EQUILIBRIUM :

      COMP             F(I)          X(I)          Y(I)
K(I)
      PROPA-01         1.0000        1.0000        1.0000
1.0000

 BLOCK:  F3       MODEL: FLASH2
 ------------------------------
   INLET STREAM:          P18
   OUTLET VAPOR STREAM:   P19
   OUTLET LIQUID STREAM:  P20
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            60663.7         60663.7
0.00000
       MASS(LB/HR   )           0.267506E+07    0.267506E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.308613E+10   -0.311091E+10
0.796688E-02

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

                           ***  INPUT DATA  ***
   TWO    PHASE  PV  FLASH
   SPECIFIED PRESSURE    PSIA                              61.0000
```

```
   VAPOR FRACTION                                               0.30000
   MAXIMUM NO. ITERATIONS                                      30
   CONVERGENCE TOLERANCE
0.000100000

                          ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                      24.969
   OUTLET PRESSURE       PSIA                                   61.000
   HEAT DUTY             BTU/HR                                -
0.24784E+08
   VAPOR FRACTION                                               0.30000



   V-L PHASE EQUILIBRIUM :

      COMP             F(I)          X(I)          Y(I)
K(I)
      PROPA-01         1.0000        1.0000        1.0000
1.0000

 BLOCK:  F4       MODEL: FLASH2
 ------------------------------
   INLET STREAM:          P22
   OUTLET VAPOR STREAM:   P23
   OUTLET LIQUID STREAM:  P24
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           42464.6         42464.6
0.00000
       MASS(LB/HR   )          0.187254E+07    0.187254E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.201666E+10   -0.223352E+10
0.970935E-01

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

                         ***  INPUT DATA  ***
   TWO    PHASE  PV  FLASH
   SPECIFIED PRESSURE    PSIA                                  18.0000
   VAPOR FRACTION                                               0.30000
   MAXIMUM NO. ITERATIONS                                      30
```

```
   CONVERGENCE TOLERANCE
0.000100000

                           ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                  -34.792
   OUTLET PRESSURE       PSIA                                18.000
   HEAT DUTY             BTU/HR                            -
0.21686E+09
   VAPOR FRACTION                                           0.30000



   V-L PHASE EQUILIBRIUM :

      COMP             F(I)           X(I)           Y(I)
K(I)
      PROPA-01         1.0000         1.0000         1.0000
1.0000

 BLOCK:  F5       MODEL: FLASH2
 ------------------------------
   INLET STREAM:          MR8
   OUTLET VAPOR STREAM:   MRB1
   OUTLET LIQUID STREAM:  MRA1
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                     IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           153708.         153708.
0.00000
       MASS(LB/HR   )          0.401628E+07    0.401628E+07   -
0.347830E-15
       ENTHALPY(BTU/HR  )      -0.550088E+10   -0.551160E+10
0.194596E-02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E        0.252673E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
    UTILITIES CO2E PRODUCTION     0.00000     LB/HR
    TOTAL CO2E PRODUCTION         0.00000     LB/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE F                                -29.0000
   SPECIFIED PRESSURE    PSIA                             600.000
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE
0.000100000
```

```
                         ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                    -29.000
   OUTLET PRESSURE       PSIA                                  600.00
   HEAT DUTY             BTU/HR                              -
0.10726E+08
   VAPOR FRACTION                                             0.46986


   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)
K(I)
      METHA-01        0.40987        0.24791        0.59261
2.3905
      ETHAN-01        0.33505        0.47005        0.18273
0.38875
      PROPA-01        0.14508        0.25024        0.26432E-01
0.10563
      N2              0.11000        0.31811E-01    0.19822
6.2313

 BLOCK:  MHT1     MODEL: HEATER
 ------------------------------
   INLET STREAM:          MR2
   OUTLET STREAM:         MR3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           153708.         153708.
0.00000
       MASS(LB/HR   )         0.401628E+07    0.401628E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.476214E+10   -0.479678E+10
0.722121E-02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E         0.252673E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                F
150.000
```

```
   SPECIFIED PRESSURE                    PSIA
345.000
   MAXIMUM NO. ITERATIONS                                               30
   CONVERGENCE TOLERANCE
0.000100000



                            ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                          150.00
   OUTLET PRESSURE       PSIA                                       345.00
   HEAT DUTY             BTU/HR                                   -
0.34639E+08
   OUTLET VAPOR FRACTION                                            1.0000



   V-L PHASE EQUILIBRIUM :

      COMP             F(I)          X(I)          Y(I)
K(I)
      METHA-01         0.40987       0.17405       0.40987
5.8109
      ETHAN-01         0.33505       0.40297       0.33505
2.0517
      PROPA-01         0.14508       0.39570       0.14508
0.90473
      N2               0.11000       0.27284E-01   0.11000
9.9485

 BLOCK:  MHT2     MODEL: HEATER
 ------------------------------
   INLET STREAM:          MR4
   OUTLET STREAM:         MR5
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           153708.         153708.
0.00000
       MASS(LB/HR   )          0.401628E+07    0.401628E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.466680E+10   -0.492752E+10
0.529115E-01

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E        0.252673E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
```

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

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                F
107.000
   SPECIFIED PRESSURE                   PSIA
611.000
   MAXIMUM NO. ITERATIONS                                           30
   CONVERGENCE TOLERANCE
0.000100000



                           ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                        107.00
   OUTLET PRESSURE       PSIA                                     611.00
   HEAT DUTY             BTU/HR                                 -
0.26072E+09
   OUTLET VAPOR FRACTION                                          1.0000


   V-L PHASE EQUILIBRIUM :

      COMP              F(I)           X(I)           Y(I)
K(I)
      METHA-01         0.40987        0.21336        0.40987
2.5335
      ETHAN-01         0.33505        0.40760        0.33505
1.0841
      PROPA-01         0.14508        0.34196        0.14508
0.55955
      N2               0.11000        0.37077E-01    0.11000
3.9128

 BLOCK:  MHX1     MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             MR5
   OUTLET STREAM:            MR6
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:             P17
   OUTLET STREAM:            P18
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
```

```
                     ***  MASS AND ENERGY BALANCE  ***
                                   IN             OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           214372.        214372.
0.00000
       MASS(LB/HR   )          0.669134E+07   0.669134E+07
0.00000
       ENTHALPY(BTU/HR  )     -0.810554E+10  -0.810554E+10   -
0.235314E-15

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E        0.252673E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
    UTILITIES CO2E PRODUCTION     0.00000     LB/HR
    TOTAL CO2E PRODUCTION         0.00000     LB/HR

                         ***  INPUT DATA  ***

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

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

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE              F                         65.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE OUTLET PRESSURE      PSIA                   606.0000
     COLD SIDE PRESSURE DROP        PSI                      0.0000

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

```
                         ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
   MR5       ----->|               HOT                  |-----> MR6
   T=  1.0700D+02  |                                    |       T=
6.5000D+01
   P=  6.1100D+02  |                                    |       P=
6.0600D+02
   V=  1.0000D+00  |                                    |       V=
1.0000D+00
                   |                                    |
   P18       <-----|               COLD                 |<----- P17
   T=  2.4969D+01  |                                    |       T=
2.4969D+01
   P=  6.1000D+01  |                                    |       P=
6.1000D+01
   V=  3.5561D-01  |                                    |       V=
1.4943D-01
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY          BTU/HR            91885170.8084
     CALCULATED (REQUIRED) AREA    SQFT                 10485.3061
     ACTUAL EXCHANGER AREA         SQFT                 10485.3061
     PER CENT OVER-DESIGN                                   0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)   BTU/HR-SQFT-R          149.6937
     UA (DIRTY)                    BTU/HR-R           1569583.7994

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                 1.0000
     LMTD (CORRECTED)              F                       58.5411
     NUMBER OF SHELLS IN SERIES                         1

   PRESSURE DROP:
     HOTSIDE, TOTAL                PSI                      5.0000
     COLDSIDE, TOTAL               PSI                      0.0000

                         ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                    HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                          VAP                              |
HOT OUT
```

```
 ------> |
|------>
  107.0  |                                                        |
65.0
         |                                                        |
 COLDOUT |                          BOIL                          |
COLDIN
 <------ |
|<------
   25.0  |                                                        |
25.0
         |                                                        |
         -------------------------------------------------------------
                                    COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              BTU/HR          SQFT        F         BTU/HR-SQFT-R
BTU/HR-R
     1   91885170.808     10485.3061      58.5411   149.6937
1569583.7994

 BLOCK:  MHX2     MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:            MR6
   OUTLET STREAM:           MR7
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:            P21
   OUTLET STREAM:           P22
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            196173.         196173.
0.00000
       MASS(LB/HR   )           0.588883E+07    0.588883E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.729064E+10   -0.729064E+10
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E         0.252673E+08  LB/HR
```

```
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                         ***  INPUT DATA  ***

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

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

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE               F                        16.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE OUTLET PRESSURE      PSIA                   601.0000
     COLD SIDE PRESSURE DROP        PSI                      0.0000

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

                       ***  OVERALL RESULTS  ***

   STREAMS:
                  --------------------------------------
                  |                                    |
   MR6       ----->|               HOT                  |-----> MR7
   T=  6.5000D+01  |                                    |       T=
1.6000D+01
   P=  6.0600D+02  |                                    |       P=
6.0100D+02
   V=  1.0000D+00  |                                    |       V=
7.3413D-01
                  |                                    |
```

```
   P22       <-----|                COLD                 |<----- P21
   T= -3.4792D+01  |                                     |       T= -
3.4792D+01
   P=  1.8000D+01  |                                     |       P=
1.8000D+01
   V=  9.3020D-01  |                                     |       V=
1.9043D-01
                   --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY            BTU/HR           254565704.6342
     CALCULATED (REQUIRED) AREA      SQFT                 24685.4109
     ACTUAL EXCHANGER AREA           SQFT                 24685.4109
     PER CENT OVER-DESIGN                                     0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     BTU/HR-SQFT-R          149.6937
     UA (DIRTY)                      BTU/HR-R           3695249.4155

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                   1.0000
     LMTD (CORRECTED)                F                       68.8900
     NUMBER OF SHELLS IN SERIES                             1

   PRESSURE DROP:
     HOTSIDE, TOTAL                  PSI                      5.0000
     COLDSIDE, TOTAL                 PSI                      0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                             HOT
         -------------------------------------------------------------
         |                             |                             |
  HOT IN |             VAP             |             COND            |
HOT OUT
  ------> |                            |
|------>
   65.0  |                         49.6|                             |
16.0
         |                             |                             |
 COLDOUT |             BOIL            |             BOIL            |
COLDIN
  <------ |                            |
|<------
  -34.8  |                        -34.8|                             |
-34.8
         |                             |                             |
         -------------------------------------------------------------
                                             COLD
```

```
   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              BTU/HR          SQFT        F         BTU/HR-SQFT-R
BTU/HR-R
     1   35701506.188      2595.4369      91.8909   149.6937
388520.4379
     2  218864198.446     22089.9740      66.1875   149.6937
3306728.9777

 BLOCK:  MHX3     MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:            MR7
   OUTLET STREAM:           MR8
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:            P25
   OUTLET STREAM:           P26
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           183433.         183433.
0.00000
       MASS(LB/HR   )          0.532706E+07    0.532706E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.690970E+10   -0.690970E+10   -
0.276039E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E        0.252673E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

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

   FLASH SPECS FOR COLD SIDE:
```

```
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE
0.000100000

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE              F                    -27.0000
     LMTD CORRECTION FACTOR                              1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE OUTLET PRESSURE      PSIA                596.0000
     COLD SIDE PRESSURE DROP        PSI                   0.0000

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

                         ***  OVERALL RESULTS  ***

   STREAMS:
                  --------------------------------------
                  |                                    |
   MR7      ----->|              HOT                   |-----> MR8
   T=  1.6000D+01 |                                    |       T= -
2.7000D+01
   P=  6.0100D+02 |                                    |       P=
5.9600D+02
   V=  7.3413D-01 |                                    |       V=
4.8277D-01
                  |                                    |
   P26      <-----|              COLD                  |<----- P25
   T= -6.9973D+01 |                                    |       T= -
8.9349D+01
   P=  4.0000D+00 |                                    |       P=
4.0000D+00
   V=  1.0000D+00 |                                    |       V=
1.5144D-01
                  --------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY           BTU/HR          226900396.0138
     CALCULATED (REQUIRED) AREA     SQFT                 18531.7997
     ACTUAL EXCHANGER AREA          SQFT                 18531.7997
```

```
    PER CENT OVER-DESIGN                                          0.0000

  HEAT TRANSFER COEFFICIENT:
    AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R                149.6937
    UA (DIRTY)                     BTU/HR-R                 2774092.8552

  LOG-MEAN TEMPERATURE DIFFERENCE:
    LMTD CORRECTION FACTOR                                        1.0000
    LMTD (CORRECTED)               F                             81.7926
    NUMBER OF SHELLS IN SERIES                                    1

  PRESSURE DROP:
    HOTSIDE, TOTAL                 PSI                            5.0000
    COLDSIDE, TOTAL                PSI                            0.0000

                        ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                                        HOT
          -------------------------------------------------------------
          |                             |                             |
 HOT IN   |            COND             |            COND             |
HOT OUT
 ------>  |                             |
|------>
   16.0   |                        14.5|                             |
-27.0
          |                             |                             |
 COLDOUT  |            VAP              |            BOIL             |
COLDIN
 <------  |                             |
|<------
  -70.0   |                       -89.3|                             |
-89.3
          |                             |                             |
          -------------------------------------------------------------
                                        COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE       HEAT DUTY       AREA        LMTD        AVERAGE U        UA
             BTU/HR          SQFT         F          BTU/HR-SQFT-R
BTU/HR-R
     1    8602235.113       607.1604      94.6465   149.6937
90888.0579
     2  218298160.901     17924.6393      81.3572   149.6937
2683204.7972

 BLOCK:  MIX      MODEL: MIXER
 -----------------------------
   INLET STREAMS:         MRB5        MRA3
```

```
   OUTLET STREAM:          MRAB
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           153708.         153708.
0.00000
       MASS(LB/HR   )          0.401628E+07    0.401628E+07
0.231887E-15
       ENTHALPY(BTU/HR  )      -0.592746E+10   -0.592746E+10   -
0.321782E-15

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.252673E+08  LB/HR
    PRODUCT STREAMS CO2E        0.252673E+08  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:  PHT      MODEL: HEATER
 ------------------------------
   INLET STREAM:           P1
   OUTLET STREAM:          P2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           142738.         142738.
0.00000
       MASS(LB/HR   )          0.629426E+07    0.629426E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.632913E+10   -0.731869E+10
0.135210

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

```
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                F
100.0000
   SPECIFIED PRESSURE                   PSIA
195.000
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE
0.000100000



                           ***  RESULTS  ***
   OUTLET TEMPERATURE    F                                    100.00
   OUTLET PRESSURE       PSIA                                 195.00
   HEAT DUTY             BTU/HR                              -
0.98956E+09
   OUTLET VAPOR FRACTION                                      0.0000



   V-L PHASE EQUILIBRIUM :

      COMP             F(I)          X(I)          Y(I)
K(I)
      PROPA-01         1.0000        1.0000        1.0000
0.98443

 BLOCK:  PHX1     MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             NG1
   OUTLET STREAM:            NG2
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:             P3
   OUTLET STREAM:            P4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN             OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           224675.        224675.
0.00000
```

```
      MASS(LB/HR   )           0.766651E+07    0.766651E+07
0.00000
      ENTHALPY(BTU/HR  )      -0.997202E+10   -0.997202E+10
0.191270E-15

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.315414E+08  LB/HR
    PRODUCT STREAMS CO2E         0.315414E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                        ***  INPUT DATA  ***

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

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

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE               F                       70.0000
     LMTD CORRECTION FACTOR                                 1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE OUTLET PRESSURE      PSIA                  730.0000
     COLD SIDE PRESSURE DROP        PSI                     0.0000

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

                      ***  OVERALL RESULTS  ***

   STREAMS:
                   --------------------------------------
                   |                                    |
```

```
   NG1       ----->|               HOT                |-----> NG2
   T=  1.0700D+02  |                                  |       T=
7.0000D+01
   P=  7.3500D+02  |                                  |       P=
7.3000D+02
   V=  1.0000D+00  |                                  |       V=
1.0000D+00
                   |                                  |
   P4        <-----|               COLD               |<----- P3
   T=  6.3880D+01  |                                  |       T=
6.3880D+01
   P=  1.1500D+02  |                                  |       P=
1.1500D+02
   V=  1.9822D-01  |                                  |       V=
1.6596D-01
                   ------------------------------------

   DUTY AND AREA:
     CALCULATED HEAT DUTY            BTU/HR           30900953.4143
     CALCULATED (REQUIRED) AREA      SQFT                10893.1424
     ACTUAL EXCHANGER AREA           SQFT                10893.1424
     PER CENT OVER-DESIGN                                    0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     BTU/HR-SQFT-R         149.6937
     UA (DIRTY)                      BTU/HR-R          1630634.3100

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                  1.0000
     LMTD (CORRECTED)                F                      18.9503
     NUMBER OF SHELLS IN SERIES                             1

   PRESSURE DROP:
     HOTSIDE, TOTAL                  PSI                     5.0000
     COLDSIDE, TOTAL                 PSI                     0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                      HOT
         -------------------------------------------------------------
         |                                                           |
 HOT IN  |                           VAP                             |
HOT OUT
 ------> |
|------>
  107.0  |                                                           |
70.0
         |                                                           |
 COLDOUT |                           BOIL                            |
COLDIN
```

```
 <------ |
|<------
   63.9  |                                                 |
63.9
         |                                                 |
         -------------------------------------------------------------
                                COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              BTU/HR          SQFT        F         BTU/HR-SQFT-R
BTU/HR-R
     1   30900953.414     10893.1424      18.9503   149.6937
1630634.3100

 BLOCK:  PHX2     MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:            NG2
   OUTLET STREAM:           NG3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:            P8
   OUTLET STREAM:           P9
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            92642.6          92642.6
0.00000
       MASS(LB/HR   )          0.184432E+07    0.184432E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.324505E+10   -0.324505E+10
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.315414E+08  LB/HR
    PRODUCT STREAMS CO2E        0.315414E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

   FLASH SPECS FOR HOT SIDE:
```

```
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                   30
   CONVERGENCE TOLERANCE
0.000100000

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

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE               F                        30.0000
     LMTD CORRECTION FACTOR                                  1.00000

   PRESSURE SPECIFICATION:
     HOT  SIDE OUTLET PRESSURE     PSIA                    725.0000
     COLD SIDE PRESSURE DROP       PSI                       0.0000

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

                        ***  OVERALL RESULTS  ***

   STREAMS:
                ---------------------------------------
                |                                     |
   NG2      ----->|              HOT                   |-----> NG3
   T=  7.0000D+01  |                                     |       T=
3.0000D+01
   P=  7.3000D+02  |                                     |       P=
7.2500D+02
   V=  1.0000D+00  |                                     |       V=
1.0000D+00
                |                                     |
   P9       <-----|              COLD                  |<----- P8
   T=  2.4969D+01  |                                     |       T=
2.4969D+01
   P=  6.1000D+01  |                                     |       P=
6.1000D+01
   V=  5.8222D-01  |                                     |       V=
1.4943D-01
```

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

   DUTY AND AREA:
     CALCULATED HEAT DUTY            BTU/HR              34036259.2067
     CALCULATED (REQUIRED) AREA      SQFT                   12458.7008
     ACTUAL EXCHANGER AREA           SQFT                   12458.7008
     PER CENT OVER-DESIGN                                       0.0000

   HEAT TRANSFER COEFFICIENT:
     AVERAGE COEFFICIENT (DIRTY)     BTU/HR-SQFT-R            149.6937
     UA (DIRTY)                      BTU/HR-R             1864988.4683

   LOG-MEAN TEMPERATURE DIFFERENCE:
     LMTD CORRECTION FACTOR                                     1.0000
     LMTD (CORRECTED)                F                         18.2501
     NUMBER OF SHELLS IN SERIES                                 1

   PRESSURE DROP:
     HOTSIDE, TOTAL                  PSI                        5.0000
     COLDSIDE, TOTAL                 PSI                        0.0000

                       ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                HOT
         -------------------------------------------------------------
         |                                                           |
  HOT IN |                      VAP                                  |
HOT OUT
  ------> |
|------>
   70.0  |                                                           |
30.0
         |                                                           |
 COLDOUT |                      BOIL                                 |
COLDIN
 <------ |
|<------
   25.0  |                                                           |
25.0
         |                                                           |
         -------------------------------------------------------------
                                COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA        LMTD        AVERAGE U       UA
              BTU/HR          SQFT         F          BTU/HR-SQFT-R
BTU/HR-R
     1   34036259.207     12458.7008      18.2501   149.6937
1864988.4683
```

```
 BLOCK:  PHX3     MODEL: HEATX
 -----------------------------
   HOT SIDE:
   ---------
   INLET STREAM:             NG3
   OUTLET STREAM:            NG4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
   COLD SIDE:
   ----------
   INLET STREAM:             P12
   OUTLET STREAM:            P13
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           89430.9         89430.9
0.00000
       MASS(LB/HR   )          0.170270E+07    0.170270E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.311907E+10   -0.311907E+10
0.00000

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.315414E+08  LB/HR
    PRODUCT STREAMS CO2E        0.315414E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                          ***  INPUT DATA  ***

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

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

   FLOW DIRECTION AND SPECIFICATION:
     COUNTERCURRENT   HEAT EXCHANGER
     SPECIFIED HOT OUTLET TEMP
     SPECIFIED VALUE               F                      -29.0000
```

```
  LMTD CORRECTION FACTOR                                    1.00000

PRESSURE SPECIFICATION:
  HOT  SIDE OUTLET PRESSURE      PSIA                     720.0000
  COLD SIDE PRESSURE DROP        PSI                        0.0000

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

                    ***  OVERALL RESULTS  ***

STREAMS:
                ---------------------------------------
                |                                     |
NG3       ----->|                HOT                  |-----> NG4
T=  3.0000D+01  |                                     |       T= -
2.9000D+01
P=  7.2500D+02  |                                     |       P=
7.2000D+02
V=  1.0000D+00  |                                     |       V=
1.0000D+00
                |                                     |
P13       <-----|                COLD                 |<----- P12
T=  4.9351D+00  |                                     |       T= -
3.4792D+01
P=  1.8000D+01  |                                     |       P=
1.8000D+01
V=  1.0000D+00  |                                     |       V=
1.9043D-01
                ---------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY           BTU/HR              53926388.0860
  CALCULATED (REQUIRED) AREA     SQFT                   15074.6160
  ACTUAL EXCHANGER AREA          SQFT                   15074.6160
  PER CENT OVER-DESIGN                                      0.0000

HEAT TRANSFER COEFFICIENT:
  AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R            149.6937
  UA (DIRTY)                     BTU/HR-R             2256574.3863

LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                                    1.0000
  LMTD (CORRECTED)               F                         23.8975
```

```
     NUMBER OF SHELLS IN SERIES                               1

   PRESSURE DROP:
     HOTSIDE, TOTAL               PSI                        5.0000
     COLDSIDE, TOTAL              PSI                        0.0000

                        ***  ZONE RESULTS  ***

   TEMPERATURE LEAVING EACH ZONE:

                                      HOT
         -------------------------------------------------------------
         |                             |                             |
  HOT IN |             VAP             |             VAP             |
HOT OUT
  ------> |                            |
|------>
   30.0  |                        24.5|                             |
-29.0
         |                             |                             |
  COLDOUT |            VAP             |             BOIL            |
COLDIN
  <------ |                            |
|<------
    4.9  |                       -34.8|                             |
-34.8
         |                             |                             |
         -------------------------------------------------------------
                                      COLD

   ZONE HEAT TRANSFER AND AREA:

   ZONE       HEAT DUTY       AREA       LMTD       AVERAGE U       UA
              BTU/HR          SQFT        F         BTU/HR-SQFT-R
BTU/HR-R
     1    4764158.354      800.3880      39.7633   149.6937
119813.0130
     2   49162229.732    14274.2280      23.0078   149.6937
2136761.3733

  BLOCK:  SPLIT    MODEL: FSPLIT
  ------------------------------
   INLET STREAM:          P6
   OUTLET STREAMS:        P7          P16
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

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

```
      MOLE(LBMOL/HR)            71369.1         71369.1
0.00000
      MASS(LB/HR   )          0.314713E+07    0.314713E+07
0.00000
      ENTHALPY(BTU/HR  )      -0.373884E+10   -0.373884E+10
0.00000

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

                        ***  INPUT DATA  ***

  FRACTION OF FLOW                STRM=P7       FRAC=         0.15000

                         ***  RESULTS  ***

  STREAM= P7            SPLIT=          0.15000     KEY=  0
STREAM-ORDER=   1
        P16                         0.85000           0
2

 BLOCK:  T1       MODEL: COMPR
 -----------------------------
   INLET STREAM:          MRA2
   OUTLET STREAM:         MRA3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE


**********************************************************************
*
     *
*
     *     FEED STREAM IS BELOW DEW POINT
*
     *
*

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

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

```
      MOLE(LBMOL/HR)            81487.5         81487.5
0.00000
      MASS(LB/HR   )          0.244763E+07    0.244763E+07
0.00000
      ENTHALPY(BTU/HR  )      -0.368827E+10   -0.369530E+10
0.190290E-02

                  ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E           0.810206E+07  LB/HR
    PRODUCT STREAMS CO2E        0.810206E+07  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
    UTILITIES CO2E PRODUCTION     0.00000     LB/HR
    TOTAL CO2E PRODUCTION         0.00000     LB/HR

                       ***  INPUT DATA  ***

   ISENTROPIC TURBINE
    OUTLET PRESSURE  PSIA                                    49.0000
    ISENTROPIC EFFICIENCY                                     0.72000
    MECHANICAL EFFICIENCY                                     1.00000

                       ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP                 -2,763.60
    BRAKE      HORSEPOWER REQUIREMENT  HP                 -2,763.60
    NET WORK REQUIRED                  HP                 -2,763.60
    POWER LOSSES                       HP                      0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP                 -3,838.34
    CALCULATED OUTLET TEMP  F                               -188.578
    ISENTROPIC TEMPERATURE  F                               -189.723
    EFFICIENCY (POLYTR/ISENTR) USED                           0.72000
    OUTLET VAPOR FRACTION                                     0.11042
    HEAD DEVELOPED,        FT-LBF/LB                      -3,105.00
    MECHANICAL EFFICIENCY USED                                1.00000
    INLET HEAT CAPACITY RATIO                                 1.40847
    INLET VOLUMETRIC FLOW RATE , CUFT/HR                  68,013.6
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                 572,385.
    INLET  COMPRESSIBILITY FACTOR                             0.16110
    OUTLET COMPRESSIBILITY FACTOR                             0.11831
    AV. ISENT. VOL. EXPONENT                                  1.19800
    AV. ISENT. TEMP EXPONENT                                  1.02896
    AV. ACTUAL VOL. EXPONENT                                  1.17605
    AV. ACTUAL TEMP EXPONENT                                  1.02718

 BLOCK:  T2       MODEL: COMPR
 -----------------------------
   INLET STREAM:          MRB3
   OUTLET STREAM:         MRB4
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE
```

```
*********************************************************************
*
     *
*
     *     FEED STREAM IS BELOW DEW POINT
*
     *
*

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


                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           72220.5         72220.5
0.00000
       MASS(LB/HR   )          0.156865E+07    0.156865E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.244460E+10   -0.244805E+10
0.141116E-02

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.171653E+08  LB/HR
    PRODUCT STREAMS CO2E         0.171653E+08  LB/HR
    NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
    UTILITIES CO2E PRODUCTION     0.00000      LB/HR
    TOTAL CO2E PRODUCTION         0.00000      LB/HR

                           ***  INPUT DATA  ***

   ISENTROPIC TURBINE
    OUTLET PRESSURE  PSIA                                     51.0000
    ISENTROPIC EFFICIENCY                                      0.72000
    MECHANICAL EFFICIENCY                                      1.00000

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  HP               -1,357.70
    BRAKE      HORSEPOWER REQUIREMENT  HP               -1,357.70
    NET WORK REQUIRED                  HP               -1,357.70
    POWER LOSSES                       HP                    0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  HP               -1,885.70
    CALCULATED OUTLET TEMP  F                             -267.580
    ISENTROPIC TEMPERATURE  F                             -268.057
    EFFICIENCY (POLYTR/ISENTR) USED                          0.72000
    OUTLET VAPOR FRACTION                                    0.035325
    HEAD DEVELOPED,       FT-LBF/LB                     -2,380.18
    MECHANICAL EFFICIENCY USED                               1.00000
```

```
    INLET HEAT CAPACITY RATIO                                1.49225
    INLET VOLUMETRIC FLOW RATE , CUFT/HR                 44,832.9
    OUTLET VOLUMETRIC FLOW RATE, CUFT/HR                139,446.
    INLET  COMPRESSIBILITY FACTOR                            0.17559
    OUTLET COMPRESSIBILITY FACTOR                            0.047770
    AV. ISENT. VOL. EXPONENT                                 2.39981
    AV. ISENT. TEMP EXPONENT                                 1.01279
    AV. ACTUAL VOL. EXPONENT                                 2.17240
    AV. ACTUAL TEMP EXPONENT                                 1.01175

 BLOCK:  V1       MODEL: VALVE
 -----------------------------
   INLET STREAM:          P2
   OUTLET STREAM:         P3
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           142738.         142738.
0.00000
       MASS(LB/HR   )          0.629426E+07    0.629426E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.731869E+10   -0.731869E+10
0.00000

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

                          ***  INPUT DATA  ***

    VALVE OUTLET PRESSURE     PSIA                        115.000
    VALVE FLOW COEF CALC.                                 NO

                          FLASH SPECIFICATIONS:
    NPHASE                                                  2
    MAX NUMBER OF ITERATIONS                               30
    CONVERGENCE TOLERANCE
0.000100000

                          ***  RESULTS  ***

    VALVE PRESSURE DROP       PSI                          80.0000

 BLOCK:  V2       MODEL: VALVE
 -----------------------------
```

```
   INLET STREAM:           P7
   OUTLET STREAM:          P8
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           10705.4         10705.4
0.00000
       MASS(LB/HR   )           472069.         472069.
0.00000
       ENTHALPY(BTU/HR  )      -0.560826E+09   -0.560826E+09
0.00000

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

                          ***  INPUT DATA  ***

    VALVE OUTLET PRESSURE     PSIA                          61.0000
    VALVE FLOW COEF CALC.                                  NO

                          FLASH SPECIFICATIONS:
    NPHASE                                                   2
    MAX NUMBER OF ITERATIONS                                30
    CONVERGENCE TOLERANCE
0.000100000

                          ***  RESULTS  ***

    VALVE PRESSURE DROP       PSI                           54.0000

 BLOCK:  V3       MODEL: VALVE
 -----------------------------
   INLET STREAM:           P11
   OUTLET STREAM:          P12
   PROPERTY OPTION SET:    SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           7493.75         7493.75
0.00000
```

```
      MASS(LB/HR   )            330448.         330448.
0.00000
      ENTHALPY(BTU/HR  )      -0.400804E+09   -0.400804E+09
0.00000

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

                        ***  INPUT DATA  ***

   VALVE OUTLET PRESSURE     PSIA                          18.0000
   VALVE FLOW COEF CALC.                                  NO

                        FLASH SPECIFICATIONS:
   NPHASE                                                   2
   MAX NUMBER OF ITERATIONS                                30
   CONVERGENCE TOLERANCE
0.000100000

                        ***  RESULTS  ***

   VALVE PRESSURE DROP       PSI                           43.0000

 BLOCK:  V4       MODEL: VALVE
 -----------------------------
   INLET STREAM:          P16
   OUTLET STREAM:         P17
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            60663.7         60663.7
0.00000
      MASS(LB/HR   )          0.267506E+07    0.267506E+07
0.00000
      ENTHALPY(BTU/HR  )      -0.317801E+10   -0.317801E+10
0.00000

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

*** INPUT DATA ***

VALVE OUTLET PRESSURE PSIA 61.0000
VALVE FLOW COEF CALC. NO

FLASH SPECIFICATIONS:
NPHASE 2
MAX NUMBER OF ITERATIONS 30
CONVERGENCE TOLERANCE
0.000100000

*** RESULTS ***

VALVE PRESSURE DROP PSI 54.0000

BLOCK: V5 MODEL: VALVE

INLET STREAM: P20
OUTLET STREAM: P21
PROPERTY OPTION SET: SRK SOAVE-REDLICH-KWONG EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	42464.6	42464.6	0.00000
MASS(LB/HR)	0.187254E+07	0.187254E+07	0.00000
ENTHALPY(BTU/HR)	-0.227123E+10	-0.227123E+10	0.00000

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

VALVE OUTLET PRESSURE PSIA 18.0000
VALVE FLOW COEF CALC. NO

FLASH SPECIFICATIONS:
NPHASE 2
MAX NUMBER OF ITERATIONS 30
CONVERGENCE TOLERANCE
0.000100000

*** RESULTS ***

```
   VALVE PRESSURE DROP       PSI                          43.0000

 BLOCK:  V6       MODEL: VALVE
 -----------------------------
   INLET STREAM:          P24
   OUTLET STREAM:         P25
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           29725.2         29725.2
0.00000
       MASS(LB/HR   )          0.131078E+07    0.131078E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.163573E+10   -0.163573E+10
0.00000

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

                         ***  INPUT DATA  ***

    VALVE OUTLET PRESSURE     PSIA                          4.00000
    VALVE FLOW COEF CALC.                                 NO

                         FLASH SPECIFICATIONS:
    NPHASE                                                  2
    MAX NUMBER OF ITERATIONS                               30
    CONVERGENCE TOLERANCE
0.000100000

                         ***  RESULTS  ***

    VALVE PRESSURE DROP       PSI                          14.0000

 BLOCK:  V7       MODEL: VALVE
 -----------------------------
   INLET STREAM:          NG6
   OUTLET STREAM:         NG7
   PROPERTY OPTION SET:   SRK       SOAVE-REDLICH-KWONG EQUATION OF
STATE

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

```
                                      IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)            81937.2         81937.2
0.00000
       MASS(LB/HR   )          0.137225E+07    0.137225E+07
0.00000
       ENTHALPY(BTU/HR  )      -0.318724E+10   -0.318724E+10
0.00000

                          ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.315414E+08  LB/HR
    PRODUCT STREAMS CO2E         0.315414E+08  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  ***

    VALVE OUTLET PRESSURE     PSIA                          75.0000
    VALVE FLOW COEF CALC.                                  NO

                          FLASH SPECIFICATIONS:
    NPHASE                                                   2
    MAX NUMBER OF ITERATIONS                                30
    CONVERGENCE TOLERANCE
0.000100000

                          ***  RESULTS  ***

    VALVE PRESSURE DROP       PSI                          645.000
```

MR1 MR2 MR3 MR4 MR5

STREAM ID	MR1	MR2	MR3	MR4	MR5
FROM :	CHX1	C6	MHT1	C7	MHT2
TO :	C6	MHT1	C7	MHT2	MHX1
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
METHA-01	6.3000+04	6.3000+04	6.3000+04	6.3000+04	6.3000+04
ETHAN-01	5.1500+04	5.1500+04	5.1500+04	5.1500+04	5.1500+04
PROPA-01	2.2300+04	2.2300+04	2.2300+04	2.2300+04	2.2300+04
N2	1.6908+04	1.6908+04	1.6908+04	1.6908+04	1.6908+04
TOTAL FLOW:					
LBMOL/HR	1.5371+05	1.5371+05	1.5371+05	1.5371+05	1.5371+05
LB/HR	4.0163+06	4.0163+06	4.0163+06	4.0163+06	4.0163+06
CUFT/HR	1.3029+07	2.7769+06	2.7186+06	1.7166+06	1.2859+06
STATE VARIABLES:					
TEMP F	-57.8651	167.8058	150.0000	228.8101	107.0000
PRES PSIA	49.0000	350.0000	345.0000	615.0000	611.0000
VFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
LFRAC	0.0	0.0	0.0	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-3.3226+04	-3.0982+04	-3.1207+04	-3.0361+04	-3.2058+04
BTU/LB	-1271.5817	-1185.7077	-1194.3322	-1161.9700	-1226.8864
BTU/HR	-5.1070+09	-4.7621+09	-4.7968+09	-4.6668+09	-4.9275+09
ENTROPY:					
BTU/LBMOL-R	-34.2008	-33.5028	-33.8404	-33.6051	-36.3044

BTU/LB-R	-1.3089	-1.2822	-1.2951	-1.2861	-1.3894
DENSITY:					
LBMOL/CUFT	1.1797-02	5.5353-02	5.6538-02	8.9541-02	0.1195
LB/CUFT	0.3082	1.4463	1.4773	2.3396	3.1233
AVG MW	26.1293	26.1293	26.1293	26.1293	26.1293

MR6 MR7 MR8 MRA1 MRA2

STREAM ID	MR6	MR7	MR8	MRA1	MRA2
FROM :	MHX1	MHX2	MHX3	F5	CHX1
TO :	MHX2	MHX3	F5	CHX1	T1
MAX CONV. ERROR:	0.0	0.0	-4.1924-08	0.0	0.0
SUBSTREAM: MIXED					
PHASE:	VAPOR	MIXED	MIXED	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
METHA-01	6.3000+04	6.3000+04	6.3000+04	2.0201+04	2.0201+04
ETHAN-01	5.1500+04	5.1500+04	5.1500+04	3.8303+04	3.8303+04
PROPA-01	2.2300+04	2.2300+04	2.2300+04	2.0391+04	2.0391+04
N2	1.6908+04	1.6908+04	1.6908+04	2592.1867	2592.1867
TOTAL FLOW:					
LBMOL/HR	1.5371+05	1.5371+05	1.5371+05	8.1487+04	8.1487+04
LB/HR	4.0163+06	4.0163+06	4.0163+06	2.4476+06	2.4476+06
CUFT/HR	1.1178+06	7.9053+05	5.4051+05	8.8351+04	6.8014+04
STATE VARIABLES:					
TEMP F	65.0000	16.0000	-27.0000	-29.0000	-170.0000
PRES PSIA	606.0000	601.0000	596.0000	600.0000	600.0000
VFRAC	1.0000	0.7341	0.4828	0.0	0.0
LFRAC	0.0	0.2659	0.5172	1.0000	1.0000

SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-3.2655+04	-3.4312+04	-3.5788+04	-4.2523+04	-4.5262+04
BTU/LB	-1249.7645	-1313.1479	-1369.6430	-1415.6883	-1506.8729
BTU/HR	-5.0194+09	-5.2740+09	-5.5009+09	-3.4651+09	-3.6883+09
ENTROPY:					
BTU/LBMOL-R	-37.3875	-40.7146	-43.9528	-57.4963	-65.1510
BTU/LB-R	-1.4309	-1.5582	-1.6821	-1.9142	-2.1690
DENSITY:					
LBMOL/CUFT	0.1375	0.1944	0.2844	0.9223	1.1981
LB/CUFT	3.5931	5.0805	7.4306	27.7034	35.9874
AVG MW	26.1293	26.1293	26.1293	30.0369	30.0369

MRA3 MRAB MRB1 MRB2 MRB3

STREAM ID	MRA3	MRAB	MRB1	MRB2	MRB3
FROM :	T1	MIX	F5	CHX1	CHX2
TO :	MIX	CHX1	CHX1	CHX2	T2
SUBSTREAM: MIXED					
PHASE:	MIXED	MIXED	VAPOR	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
METHA-01	2.0201+04	6.3000+04	4.2799+04	4.2799+04	4.2799+04
ETHAN-01	3.8303+04	5.1500+04	1.3197+04	1.3197+04	1.3197+04
PROPA-01	2.0391+04	2.2300+04	1908.9552	1908.9552	1908.9552
N2	2592.1867	1.6908+04	1.4316+04	1.4316+04	1.4316+04
TOTAL FLOW:					
LBMOL/HR	8.1487+04	1.5371+05	7.2221+04	7.2221+04	7.2221+04
LB/HR	2.4476+06	4.0163+06	1.5687+06	1.5687+06	1.5687+06
CUFT/HR	5.7238+05	3.5200+06	4.3620+05	5.5718+04	4.4833+04
STATE VARIABLES:					

TEMP F	-188.5780	-192.6049	-29.0000	-170.0000	-262.0000
PRES PSIA	49.0000	49.0000	600.0000	600.0000	600.0000
VFRAC	0.1104	0.4006	1.0000	0.0	0.0
LFRAC	0.8896	0.5994	0.0	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-4.5348+04	-3.8563+04	-2.8337+04	-3.2426+04	-3.3849+04
BTU/LB	-1509.7458	-1475.8557	-1304.6339	-1492.8937	-1558.4060
BTU/HR	-3.6953+09	-5.9275+09	-2.0465+09	-2.3418+09	-2.4446+09
ENTROPY:					
BTU/LBMOL-R	-65.0269	-49.9217	-29.0283	-40.5155	-46.3988
BTU/LB-R	-2.1649	-1.9106	-1.3365	-1.8653	-2.1362
DENSITY:					
LBMOL/CUFT	0.1424	4.3667-02	0.1656	1.2962	1.6109
LB/CUFT	4.2762	1.1410	3.5962	28.1533	34.9889
AVG MW	30.0369	26.1293	21.7203	21.7203	21.7203

MRB4 MRB5 NG1 NG2 NG3

STREAM ID	MRB4	MRB5	NG1	NG2	NG3
FROM :	T2	CHX2	----	PHX1	PHX2
TO :	CHX2	MIX	PHX1	PHX2	PHX3
SUBSTREAM: MIXED					
PHASE:	MIXED	MIXED	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
METHA-01	4.2799+04	4.2799+04	7.8643+04	7.8643+04	7.8643+04
ETHAN-01	1.3197+04	1.3197+04	2470.4681	2470.4681	2470.4681
PROPA-01	1908.9552	1908.9552	823.4894	823.4894	823.4894
N2	1.4316+04	1.4316+04	0.0	0.0	0.0

TOTAL FLOW:					
LBMOL/HR	7.2221+04	7.2221+04	8.1937+04	8.1937+04	8.1937+04
LB/HR	1.5687+06	1.5687+06	1.3723+06	1.3723+06	1.3723+06
CUFT/HR	1.3945+05	2.7575+06	6.3055+05	5.7841+05	5.1755+05
STATE VARIABLES:					
TEMP F	-267.5799	-198.7041	107.0000	70.0000	30.0000
PRES PSIA	51.0000	51.0000	735.0000	730.0000	725.0000
VFRAC	3.5325-02	0.7265	1.0000	1.0000	1.0000
LFRAC	0.9647	0.2735	0.0	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-3.3897+04	-3.0907+04	-3.2382+04	-3.2760+04	-3.3175+04
BTU/LB	-1560.6082	-1422.9757	-1933.5541	-1956.0725	-1980.8757
BTU/HR	-2.4481+09	-2.2322+09	-2.6533+09	-2.6842+09	-2.7183+09
ENTROPY:					
BTU/LBMOL-R	-46.3018	-32.9824	-27.7719	-28.4478	-29.2512
BTU/LB-R	-2.1317	-1.5185	-1.6583	-1.6986	-1.7466
DENSITY:					
LBMOL/CUFT	0.5179	2.6191-02	0.1299	0.1417	0.1583
LB/CUFT	11.2491	0.5689	2.1763	2.3724	2.6514
AVG MW	21.7203	21.7203	16.7476	16.7476	16.7476

NG4 NG5 NG6 NG7 P1

STREAM ID	NG4	NG5	NG6	NG7	P1
FROM :	PHX3	CHX1	CHX2	V7	C5
TO :	CHX1	CHX2	V7	----	PHT
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	LIQUID	LIQUID	VAPOR
COMPONENTS: LBMOL/HR					

METHA-01	7.8643+04	7.8643+04	7.8643+04	7.8643+04	0.0
ETHAN-01	2470.4681	2470.4681	2470.4681	2470.4681	0.0
PROPA-01	823.4894	823.4894	823.4894	823.4894	1.4274+05
N2	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	8.1937+04	8.1937+04	8.1937+04	8.1937+04	1.4274+05
LB/HR	1.3723+06	1.3723+06	1.3723+06	1.3723+06	6.2943+06
CUFT/HR	4.1299+05	6.2024+04	4.8615+04	4.9436+04	3.8639+06
STATE VARIABLES:					
TEMP F	-29.0000	-170.0000	-262.0000	-258.7708	146.7917
PRES PSIA	720.0000	720.0000	720.0000	75.0000	200.0000
VFRAC	1.0000	0.0	0.0	0.0	1.0000
LFRAC	0.0	1.0000	1.0000	1.0000	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-3.3833+04	-3.7518+04	-3.8899+04	-3.8899+04	-4.4341+04
BTU/LB	-2020.1734	-2240.1926	-2322.6349	-2322.6349	-1005.5409
BTU/HR	-2.7722+09	-3.0741+09	-3.1872+09	-3.1872+09	-6.3291+09
ENTROPY:					
BTU/LBMOL-R	-30.6739	-41.1187	-46.8211	-46.4549	-67.9689
BTU/LB-R	-1.8315	-2.4552	-2.7957	-2.7738	-1.5414
DENSITY:					
LBMOL/CUFT	0.1984	1.3211	1.6854	1.6574	3.6941-02
LB/CUFT	3.3227	22.1246	28.2267	27.7583	1.6290
AVG MW	16.7476	16.7476	16.7476	16.7476	44.0965

P10 P11 P12 P13 P14

STREAM ID	P10	P11	P12	P13	P14

FROM :	F2	F2	V3	PHX3	C3
TO :	C4	V3	PHX3	C3	C4
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	MIXED	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
METHA-01	0.0	0.0	0.0	0.0	0.0
ETHAN-01	0.0	0.0	0.0	0.0	0.0
PROPA-01	3211.6085	7493.7532	7493.7532	7493.7532	4.9958+04
N2	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	3211.6085	7493.7532	7493.7532	7493.7532	4.9958+04
LB/HR	1.4162+05	3.3045+05	3.3045+05	3.3045+05	2.2030+06
CUFT/HR	2.4835+05	9960.6738	3.5532+05	2.0152+06	4.6587+06
STATE VARIABLES:					
TEMP F	24.9692	24.9692	-34.7916	4.9351	103.4186
PRES PSIA	61.0000	61.0000	18.0000	18.0000	61.0000
VFRAC	1.0000	0.0	0.1904	1.0000	1.0000
LFRAC	0.0	1.0000	0.8096	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-4.6139+04	-5.3485+04	-5.3485+04	-4.6289+04	-4.4724+04
BTU/LB	-1046.3156	-1212.9107	-1212.9107	-1049.7191	-1014.2231
BTU/HR	-1.4818+08	-4.0080+08	-4.0080+08	-3.4688+08	-2.2343+09
ENTROPY:					
BTU/LBMOL-R	-69.2177	-84.3759	-84.1151	-67.2444	-66.5139
BTU/LB-R	-1.5697	-1.9134	-1.9075	-1.5249	-1.5084
DENSITY:					
LBMOL/CUFT	1.2932-02	0.7523	2.1090-02	3.7186-03	1.0724-02
LB/CUFT	0.5702	33.1753	0.9300	0.1640	0.4729

AVG MW	44.0965	44.0965	44.0965	44.0965	44.0965

P15 P16 P17 P18 P19

STREAM ID	P15	P16	P17	P18	P19
FROM :	C4	SPLIT	V4	MHX1	F3
TO :	C5	V4	MHX1	F3	C4
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	MIXED	MIXED	VAPOR
COMPONENTS: LBMOL/HR					
METHA-01	0.0	0.0	0.0	0.0	0.0
ETHAN-01	0.0	0.0	0.0	0.0	0.0
PROPA-01	7.1369+04	6.0664+04	6.0664+04	6.0664+04	1.8199+04
N2	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	7.1369+04	6.0664+04	6.0664+04	6.0664+04	1.8199+04
LB/HR	3.1471+06	2.6751+06	2.6751+06	2.6751+06	8.0252+05
CUFT/HR	3.5529+06	8.7083+04	7.6957+05	1.7202+06	1.4073+06
STATE VARIABLES:					
TEMP F	132.0367	63.8804	24.9692	24.9692	24.9692
PRES PSIA	115.0000	115.0000	61.0000	61.0000	61.0000
VFRAC	1.0000	0.0	0.1494	0.3556	1.0000
LFRAC	0.0	1.0000	0.8506	0.6444	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-4.4348+04	-5.2387+04	-5.2387+04	-5.0873+04	-4.6139+04
BTU/LB	-1005.6998	-1188.0161	-1188.0161	-1153.6672	-1046.3156
BTU/HR	-3.1651+09	-3.1780+09	-3.1780+09	-3.0861+09	-8.3969+08
ENTROPY:					

```
   BTU/LBMOL-R           -67.0249   -82.2272   -82.1107   -78.9854   -
69.2177
   BTU/LB-R               -1.5200    -1.8647    -1.8621    -1.7912    -
1.5697
 DENSITY:
   LBMOL/CUFT           2.0087-02     0.6966  7.8828-02  3.5266-02
1.2932-02
   LB/CUFT                 0.8858    30.7184     3.4760     1.5551
0.5702
 AVG MW                   44.0965    44.0965    44.0965    44.0965
44.0965

 P2 P20 P21 P22 P23
 ------------------

 STREAM ID                P2         P20        P21        P22
P23
 FROM :                   PHT        F3         V5         MHX2
F4
 TO   :                   V1         V5         MHX2       F4
C3

 SUBSTREAM: MIXED
 PHASE:                   LIQUID     LIQUID     MIXED      MIXED
VAPOR
 COMPONENTS: LBMOL/HR
   METHA-01                 0.0        0.0        0.0        0.0
0.0
   ETHAN-01                 0.0        0.0        0.0        0.0
0.0
   PROPA-01             1.4274+05  4.2465+04  4.2465+04  4.2465+04
1.2739+04
   N2                       0.0        0.0        0.0        0.0
0.0
 TOTAL FLOW:
   LBMOL/HR             1.4274+05  4.2465+04  4.2465+04  4.2465+04
1.2739+04
   LB/HR                6.2943+06  1.8725+06  1.8725+06  1.8725+06
5.6176+05
   CUFT/HR              2.2437+05  5.6444+04  2.0135+06  9.6352+06
3.1063+06
 STATE VARIABLES:
   TEMP   F              100.0000    24.9692   -34.7916   -34.7916   -
34.7916
   PRES   PSIA           195.0000    61.0000    18.0000    18.0000
18.0000
   VFRAC                    0.0        0.0       0.1904     0.9302
1.0000
   LFRAC                   1.0000     1.0000     0.8096  6.9803-02
0.0
   SFRAC                    0.0        0.0        0.0        0.0
0.0
```

ENTHALPY:					
BTU/LBMOL	-5.1274+04	-5.3485+04	-5.3485+04	-4.7490+04	-4.6925+04
BTU/LB	-1162.7575	-1212.9107	-1212.9107	-1076.9640	-1064.1364
BTU/HR	-7.3187+09	-2.2712+09	-2.2712+09	-2.0167+09	-5.9779+08
ENTROPY:					
BTU/LBMOL-R	-80.2144	-84.3759	-84.1151	-70.0057	-68.6744
BTU/LB-R	-1.8191	-1.9134	-1.9075	-1.5876	-1.5574
DENSITY:					
LBMOL/CUFT	0.6362	0.7523	2.1090-02	4.4072-03	4.1011-03
LB/CUFT	28.0532	33.1753	0.9300	0.1943	0.1808
AVG MW	44.0965	44.0965	44.0965	44.0965	44.0965

P24 P25 P26 P27 P3

STREAM ID	P24	P25	P26	P27	P3
FROM :	F4	V6	MHX3	C2	V1
TO :	V6	MHX3	C2	C3	PHX1
SUBSTREAM: MIXED					
PHASE:	LIQUID	MIXED	VAPOR	VAPOR	MIXED
COMPONENTS: LBMOL/HR					
METHA-01	0.0	0.0	0.0	0.0	0.0
ETHAN-01	0.0	0.0	0.0	0.0	0.0
PROPA-01	2.9725+04	2.9725+04	2.9725+04	2.9725+04	1.4274+05
N2	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	2.9725+04	2.9725+04	2.9725+04	2.9725+04	1.4274+05
LB/HR	1.3108+06	1.3108+06	1.3108+06	1.3108+06	6.2943+06
CUFT/HR	3.6083+04	4.4490+06	3.0761+07	8.5047+06	1.1568+06
STATE VARIABLES:					
TEMP F	-34.7916	-89.3490	-69.9731	32.4193	63.8804

```
   PRES   PSIA           18.0000     4.0000     4.0000    18.0000
115.0000
   VFRAC                  0.0        0.1514     1.0000     1.0000
0.1660
   LFRAC                  1.0000     0.8486     0.0        0.0
0.8340
   SFRAC                  0.0        0.0        0.0        0.0
0.0
 ENTHALPY:
   BTU/LBMOL          -5.5028+04 -5.5028+04 -4.7395+04 -4.5834+04 -
5.1274+04
   BTU/LB             -1247.9054 -1247.9054 -1074.8019 -1039.3956 -
1162.7575
   BTU/HR             -1.6357+09 -1.6357+09 -1.4088+09 -1.3624+09 -
7.3187+09
 ENTROPY:
   BTU/LBMOL-R          -87.7471   -87.4993   -66.9065   -66.2925   -
80.0998
   BTU/LB-R              -1.9899    -1.9843    -1.5173    -1.5034    -
1.8165
 DENSITY:
   LBMOL/CUFT             0.8238  6.6813-03  9.6633-04  3.4951-03
0.1234
   LB/CUFT               36.3270     0.2946  4.2612-02     0.1541
5.4410
 AVG MW                  44.0965    44.0965    44.0965    44.0965
44.0965

 P4 P5 P6 P7 P8
 --------------

 STREAM ID               P4         P5         P6         P7
P8
 FROM :                  PHX1       F1         F1         SPLIT
V2
 TO   :                  F1         C5         SPLIT      V2
PHX2

 SUBSTREAM: MIXED
 PHASE:                  MIXED      VAPOR      LIQUID     LIQUID
MIXED
 COMPONENTS: LBMOL/HR
   METHA-01               0.0        0.0        0.0        0.0
0.0
   ETHAN-01               0.0        0.0        0.0        0.0
0.0
   PROPA-01           1.4274+05  7.1369+04  7.1369+04  1.0705+04
1.0705+04
   N2                     0.0        0.0        0.0        0.0
0.0
 TOTAL FLOW:
```

```
   LBMOL/HR             1.4274+05  7.1369+04  7.1369+04  1.0705+04
1.0705+04
   LB/HR                6.2943+06  3.1471+06  3.1471+06  4.7207+05
4.7207+05
   CUFT/HR              1.3418+06  2.9703+06  1.0245+05  1.5368+04
1.3581+05
 STATE VARIABLES:
   TEMP   F               63.8804    63.8804    63.8804    63.8804
24.9692
   PRES   PSIA           115.0000   115.0000   115.0000   115.0000
61.0000
   VFRAC                   0.1982     1.0000     0.0        0.0
0.1494
   LFRAC                   0.8018     0.0        1.0000     1.0000
0.8506
   SFRAC                   0.0        0.0        0.0        0.0
0.0
 ENTHALPY:
   BTU/LBMOL           -5.1057+04 -4.5676+04 -5.2387+04 -5.2387+04 -
5.2387+04
   BTU/LB              -1157.8481 -1035.8204 -1188.0161 -1188.0161 -
1188.0161
   BTU/HR              -7.2878+09 -3.2599+09 -3.7388+09 -5.6083+08 -
5.6083+08
 ENTROPY:
   BTU/LBMOL-R           -79.6863   -69.4084   -82.2272   -82.2272   -
82.1107
   BTU/LB-R               -1.8071    -1.5740    -1.8647    -1.8647    -
1.8621
 DENSITY:
   LBMOL/CUFT              0.1064  2.4027-02     0.6966     0.6966
7.8828-02
   LB/CUFT                 4.6908     1.0595    30.7184    30.7184
3.4760
 AVG MW                   44.0965    44.0965    44.0965    44.0965
44.0965

 P9
 --

 STREAM ID                P9
 FROM :                   PHX2
 TO   :                   F2

 SUBSTREAM: MIXED
 PHASE:                   MIXED
 COMPONENTS: LBMOL/HR
   METHA-01                0.0
   ETHAN-01                0.0
   PROPA-01             1.0705+04
   N2                      0.0
 TOTAL FLOW:
```

```
  LBMOL/HR             1.0705+04
  LB/HR                4.7207+05
  CUFT/HR              4.8792+05
STATE VARIABLES:
  TEMP   F               24.9692
  PRES   PSIA            61.0000
  VFRAC                   0.5822
  LFRAC                   0.4178
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -4.9208+04
  BTU/LB              -1115.9159
  BTU/HR              -5.2679+08
ENTROPY:
  BTU/LBMOL-R           -75.5505
  BTU/LB-R               -1.7133
DENSITY:
  LBMOL/CUFT           2.1941-02
  LB/CUFT                 0.9675
AVG MW                   44.0965

MR1
---

STREAM ID                MR1
FROM :                   CHX1
TO   :                   C6

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  METHA-01             6.3000+04
  ETHAN-01             5.1500+04
  PROPA-01             2.2300+04
  N2                   1.6908+04
TOTAL FLOW:
  LBMOL/HR             1.5371+05
  LB/HR                4.0163+06
  CUFT/HR              1.3029+07
STATE VARIABLES:
  TEMP   F              -57.8651
  PRES   PSIA            49.0000
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -3.3226+04
  BTU/LB              -1271.5817
  BTU/HR              -5.1070+09
ENTROPY:
  BTU/LBMOL-R           -34.2008
  BTU/LB-R               -1.3089
```

```
DENSITY:
  LBMOL/CUFT           1.1797-02
  LB/CUFT                 0.3082
AVG MW                   26.1293

MR2
---

STREAM ID                MR2
FROM :                   C6
TO   :                   MHT1

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  METHA-01             6.3000+04
  ETHAN-01             5.1500+04
  PROPA-01             2.2300+04
  N2                   1.6908+04
TOTAL FLOW:
  LBMOL/HR             1.5371+05
  LB/HR                4.0163+06
  CUFT/HR              2.7769+06
STATE VARIABLES:
  TEMP   F              167.8058
  PRES   PSIA           350.0000
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -3.0982+04
  BTU/LB              -1185.7077
  BTU/HR              -4.7621+09
ENTROPY:
  BTU/LBMOL-R           -33.5028
  BTU/LB-R               -1.2822
DENSITY:
  LBMOL/CUFT           5.5353-02
  LB/CUFT                 1.4463
AVG MW                   26.1293

MR3
---

STREAM ID                MR3
FROM :                   MHT1
TO   :                   C7

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  METHA-01             6.3000+04
```

```
  ETHAN-01             5.1500+04
  PROPA-01             2.2300+04
  N2                   1.6908+04
TOTAL FLOW:
  LBMOL/HR             1.5371+05
  LB/HR                4.0163+06
  CUFT/HR              2.7186+06
STATE VARIABLES:
  TEMP   F              150.0000
  PRES   PSIA           345.0000
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -3.1207+04
  BTU/LB              -1194.3322
  BTU/HR              -4.7968+09
ENTROPY:
  BTU/LBMOL-R           -33.8404
  BTU/LB-R               -1.2951
DENSITY:
  LBMOL/CUFT           5.6538-02
  LB/CUFT                 1.4773
AVG MW                   26.1293

MR4
---

STREAM ID                MR4
FROM :                   C7
TO   :                   MHT2

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  METHA-01             6.3000+04
  ETHAN-01             5.1500+04
  PROPA-01             2.2300+04
  N2                   1.6908+04
TOTAL FLOW:
  LBMOL/HR             1.5371+05
  LB/HR                4.0163+06
  CUFT/HR              1.7166+06
STATE VARIABLES:
  TEMP   F              228.8101
  PRES   PSIA           615.0000
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -3.0361+04
  BTU/LB              -1161.9700
```

```
  BTU/HR              -4.6668+09
ENTROPY:
  BTU/LBMOL-R           -33.6051
  BTU/LB-R               -1.2861
DENSITY:
  LBMOL/CUFT          8.9541-02
  LB/CUFT                2.3396
AVG MW                  26.1293

MR5
---

STREAM ID               MR5
FROM :                  MHT2
TO   :                  MHX1

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: LBMOL/HR
  METHA-01            6.3000+04
  ETHAN-01            5.1500+04
  PROPA-01            2.2300+04
  N2                  1.6908+04
TOTAL FLOW:
  LBMOL/HR            1.5371+05
  LB/HR               4.0163+06
  CUFT/HR             1.2859+06
STATE VARIABLES:
  TEMP   F             107.0000
  PRES   PSIA          611.0000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.2058+04
  BTU/LB             -1226.8864
  BTU/HR             -4.9275+09
ENTROPY:
  BTU/LBMOL-R          -36.3044
  BTU/LB-R              -1.3894
DENSITY:
  LBMOL/CUFT             0.1195
  LB/CUFT                3.1233
AVG MW                  26.1293

MR6
---

STREAM ID               MR6
FROM :                  MHX1
TO   :                  MHX2
```

```
SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: LBMOL/HR
  METHA-01            6.3000+04
  ETHAN-01            5.1500+04
  PROPA-01            2.2300+04
  N2                  1.6908+04
TOTAL FLOW:
  LBMOL/HR            1.5371+05
  LB/HR               4.0163+06
  CUFT/HR             1.1178+06
STATE VARIABLES:
  TEMP   F              65.0000
  PRES   PSIA          606.0000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.2655+04
  BTU/LB             -1249.7645
  BTU/HR             -5.0194+09
ENTROPY:
  BTU/LBMOL-R          -37.3875
  BTU/LB-R              -1.4309
DENSITY:
  LBMOL/CUFT             0.1375
  LB/CUFT                3.5931
AVG MW                  26.1293

MR7
---

STREAM ID               MR7
FROM :                  MHX2
TO   :                  MHX3

SUBSTREAM: MIXED
PHASE:                  MIXED
COMPONENTS: LBMOL/HR
  METHA-01            6.3000+04
  ETHAN-01            5.1500+04
  PROPA-01            2.2300+04
  N2                  1.6908+04
TOTAL FLOW:
  LBMOL/HR            1.5371+05
  LB/HR               4.0163+06
  CUFT/HR             7.9053+05
STATE VARIABLES:
  TEMP   F              16.0000
  PRES   PSIA          601.0000
  VFRAC                  0.7341
  LFRAC                  0.2659
```

```
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.4312+04
  BTU/LB             -1313.1479
  BTU/HR             -5.2740+09
ENTROPY:
  BTU/LBMOL-R           -40.7146
  BTU/LB-R              -1.5582
DENSITY:
  LBMOL/CUFT             0.1944
  LB/CUFT                5.0805
AVG MW                  26.1293

MR8
---

STREAM ID               MR8
FROM :                  MHX3
TO   :                  F5


MAX CONV. ERROR:     -4.1924-08
SUBSTREAM: MIXED
PHASE:                  MIXED
COMPONENTS: LBMOL/HR
  METHA-01            6.3000+04
  ETHAN-01            5.1500+04
  PROPA-01            2.2300+04
  N2                  1.6908+04
TOTAL FLOW:
  LBMOL/HR            1.5371+05
  LB/HR               4.0163+06
  CUFT/HR             5.4051+05
STATE VARIABLES:
  TEMP   F             -27.0000
  PRES   PSIA          596.0000
  VFRAC                  0.4828
  LFRAC                  0.5172
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.5788+04
  BTU/LB             -1369.6430
  BTU/HR             -5.5009+09
ENTROPY:
  BTU/LBMOL-R           -43.9528
  BTU/LB-R              -1.6821
DENSITY:
  LBMOL/CUFT             0.2844
  LB/CUFT                7.4306
AVG MW                  26.1293

MRA1
```

```
----

STREAM ID                MRA1
FROM :                   F5
TO   :                   CHX1

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  METHA-01             2.0201+04
  ETHAN-01             3.8303+04
  PROPA-01             2.0391+04
  N2                   2592.1867
TOTAL FLOW:
  LBMOL/HR             8.1487+04
  LB/HR                2.4476+06
  CUFT/HR              8.8351+04
STATE VARIABLES:
  TEMP   F              -29.0000
  PRES   PSIA           600.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -4.2523+04
  BTU/LB              -1415.6883
  BTU/HR              -3.4651+09
ENTROPY:
  BTU/LBMOL-R           -57.4963
  BTU/LB-R               -1.9142
DENSITY:
  LBMOL/CUFT              0.9223
  LB/CUFT                27.7034
AVG MW                   30.0369

MRA2
----

STREAM ID                MRA2
FROM :                   CHX1
TO   :                   T1

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  METHA-01             2.0201+04
  ETHAN-01             3.8303+04
  PROPA-01             2.0391+04
  N2                   2592.1867
TOTAL FLOW:
  LBMOL/HR             8.1487+04
  LB/HR                2.4476+06
```

```
  CUFT/HR               6.8014+04
STATE VARIABLES:
  TEMP   F             -170.0000
  PRES   PSIA           600.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL            -4.5262+04
  BTU/LB               -1506.8729
  BTU/HR               -3.6883+09
ENTROPY:
  BTU/LBMOL-R            -65.1510
  BTU/LB-R                -2.1690
DENSITY:
  LBMOL/CUFT               1.1981
  LB/CUFT                 35.9874
AVG MW                    30.0369

MRA3
----

STREAM ID                 MRA3
FROM :                    T1
TO   :                    MIX

SUBSTREAM: MIXED
PHASE:                    MIXED
COMPONENTS: LBMOL/HR
  METHA-01              2.0201+04
  ETHAN-01              3.8303+04
  PROPA-01              2.0391+04
  N2                    2592.1867
TOTAL FLOW:
  LBMOL/HR              8.1487+04
  LB/HR                 2.4476+06
  CUFT/HR               5.7238+05
STATE VARIABLES:
  TEMP   F             -188.5780
  PRES   PSIA            49.0000
  VFRAC                   0.1104
  LFRAC                   0.8896
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL            -4.5348+04
  BTU/LB               -1509.7458
  BTU/HR               -3.6953+09
ENTROPY:
  BTU/LBMOL-R            -65.0269
  BTU/LB-R                -2.1649
DENSITY:
  LBMOL/CUFT               0.1424
```

```
  LB/CUFT                  4.2762
AVG MW                    30.0369

MRAB
----

STREAM ID                 MRAB
FROM :                    MIX
TO   :                    CHX1

SUBSTREAM: MIXED
PHASE:                    MIXED
COMPONENTS: LBMOL/HR
  METHA-01              6.3000+04
  ETHAN-01              5.1500+04
  PROPA-01              2.2300+04
  N2                    1.6908+04
TOTAL FLOW:
  LBMOL/HR              1.5371+05
  LB/HR                 4.0163+06
  CUFT/HR               3.5200+06
STATE VARIABLES:
  TEMP   F              -192.6049
  PRES   PSIA             49.0000
  VFRAC                    0.4006
  LFRAC                    0.5994
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -3.8563+04
  BTU/LB               -1475.8557
  BTU/HR               -5.9275+09
ENTROPY:
  BTU/LBMOL-R            -49.9217
  BTU/LB-R                -1.9106
DENSITY:
  LBMOL/CUFT            4.3667-02
  LB/CUFT                  1.1410
AVG MW                    26.1293

MRB1
----

STREAM ID                 MRB1
FROM :                    F5
TO   :                    CHX1

SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  METHA-01              4.2799+04
  ETHAN-01              1.3197+04
  PROPA-01              1908.9552
```

```
  N2                  1.4316+04
TOTAL FLOW:
  LBMOL/HR            7.2221+04
  LB/HR               1.5687+06
  CUFT/HR             4.3620+05
STATE VARIABLES:
  TEMP   F             -29.0000
  PRES   PSIA          600.0000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -2.8337+04
  BTU/LB             -1304.6339
  BTU/HR             -2.0465+09
ENTROPY:
  BTU/LBMOL-R          -29.0283
  BTU/LB-R              -1.3365
DENSITY:
  LBMOL/CUFT             0.1656
  LB/CUFT                3.5962
AVG MW                  21.7203

MRB2
----

STREAM ID               MRB2
FROM :                  CHX1
TO   :                  CHX2

SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  METHA-01            4.2799+04
  ETHAN-01            1.3197+04
  PROPA-01            1908.9552
  N2                  1.4316+04
TOTAL FLOW:
  LBMOL/HR            7.2221+04
  LB/HR               1.5687+06
  CUFT/HR             5.5718+04
STATE VARIABLES:
  TEMP   F            -170.0000
  PRES   PSIA          600.0000
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.2426+04
  BTU/LB             -1492.8937
  BTU/HR             -2.3418+09
ENTROPY:
```

```
  BTU/LBMOL-R           -40.5155
  BTU/LB-R               -1.8653
DENSITY:
  LBMOL/CUFT              1.2962
  LB/CUFT                28.1533
AVG MW                   21.7203

MRB3
----

STREAM ID                MRB3
FROM :                   CHX2
TO   :                   T2

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  METHA-01             4.2799+04
  ETHAN-01             1.3197+04
  PROPA-01             1908.9552
  N2                   1.4316+04
TOTAL FLOW:
  LBMOL/HR             7.2221+04
  LB/HR                1.5687+06
  CUFT/HR              4.4833+04
STATE VARIABLES:
  TEMP   F             -262.0000
  PRES   PSIA           600.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -3.3849+04
  BTU/LB              -1558.4060
  BTU/HR              -2.4446+09
ENTROPY:
  BTU/LBMOL-R           -46.3988
  BTU/LB-R               -2.1362
DENSITY:
  LBMOL/CUFT              1.6109
  LB/CUFT                34.9889
AVG MW                   21.7203

MRB4
----

STREAM ID                MRB4
FROM :                   T2
TO   :                   CHX2

SUBSTREAM: MIXED
PHASE:                   MIXED
```

```
COMPONENTS: LBMOL/HR
  METHA-01            4.2799+04
  ETHAN-01            1.3197+04
  PROPA-01            1908.9552
  N2                  1.4316+04
TOTAL FLOW:
  LBMOL/HR            7.2221+04
  LB/HR               1.5687+06
  CUFT/HR             1.3945+05
STATE VARIABLES:
  TEMP   F            -267.5799
  PRES   PSIA           51.0000
  VFRAC               3.5325-02
  LFRAC                  0.9647
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.3897+04
  BTU/LB             -1560.6082
  BTU/HR             -2.4481+09
ENTROPY:
  BTU/LBMOL-R          -46.3018
  BTU/LB-R              -2.1317
DENSITY:
  LBMOL/CUFT             0.5179
  LB/CUFT               11.2491
AVG MW                  21.7203

MRB5
----

STREAM ID               MRB5
FROM :                  CHX2
TO   :                  MIX

SUBSTREAM: MIXED
PHASE:                  MIXED
COMPONENTS: LBMOL/HR
  METHA-01            4.2799+04
  ETHAN-01            1.3197+04
  PROPA-01            1908.9552
  N2                  1.4316+04
TOTAL FLOW:
  LBMOL/HR            7.2221+04
  LB/HR               1.5687+06
  CUFT/HR             2.7575+06
STATE VARIABLES:
  TEMP   F            -198.7041
  PRES   PSIA           51.0000
  VFRAC                  0.7265
  LFRAC                  0.2735
  SFRAC                  0.0
ENTHALPY:
```

```
  BTU/LBMOL          -3.0907+04
  BTU/LB             -1422.9757
  BTU/HR             -2.2322+09
ENTROPY:
  BTU/LBMOL-R          -32.9824
  BTU/LB-R              -1.5185
DENSITY:
  LBMOL/CUFT         2.6191-02
  LB/CUFT               0.5689
AVG MW                 21.7203

NG1
---

STREAM ID              NG1
FROM :                 ----
TO   :                 PHX1

SUBSTREAM: MIXED
PHASE:                 VAPOR
COMPONENTS: LBMOL/HR
  METHA-01           7.8643+04
  ETHAN-01           2470.4681
  PROPA-01            823.4894
  N2                     0.0
TOTAL FLOW:
  LBMOL/HR           8.1937+04
  LB/HR              1.3723+06
  CUFT/HR            6.3055+05
STATE VARIABLES:
  TEMP   F            107.0000
  PRES   PSIA         735.0000
  VFRAC                 1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.2382+04
  BTU/LB             -1933.5541
  BTU/HR             -2.6533+09
ENTROPY:
  BTU/LBMOL-R          -27.7719
  BTU/LB-R              -1.6583
DENSITY:
  LBMOL/CUFT            0.1299
  LB/CUFT               2.1763
AVG MW                 16.7476

NG2
---

STREAM ID              NG2
FROM :                 PHX1
```

```
TO   :                  PHX2

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: LBMOL/HR
  METHA-01            7.8643+04
  ETHAN-01            2470.4681
  PROPA-01             823.4894
  N2                     0.0
TOTAL FLOW:
  LBMOL/HR            8.1937+04
  LB/HR               1.3723+06
  CUFT/HR             5.7841+05
STATE VARIABLES:
  TEMP   F              70.0000
  PRES   PSIA          730.0000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -3.2760+04
  BTU/LB             -1956.0725
  BTU/HR             -2.6842+09
ENTROPY:
  BTU/LBMOL-R          -28.4478
  BTU/LB-R              -1.6986
DENSITY:
  LBMOL/CUFT             0.1417
  LB/CUFT                2.3724
AVG MW                  16.7476

NG3
---

STREAM ID               NG3
FROM :                  PHX2
TO   :                  PHX3

SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: LBMOL/HR
  METHA-01            7.8643+04
  ETHAN-01            2470.4681
  PROPA-01             823.4894
  N2                     0.0
TOTAL FLOW:
  LBMOL/HR            8.1937+04
  LB/HR               1.3723+06
  CUFT/HR             5.1755+05
STATE VARIABLES:
  TEMP   F              30.0000
  PRES   PSIA          725.0000
```

```
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -3.3175+04
  BTU/LB               -1980.8757
  BTU/HR               -2.7183+09
ENTROPY:
  BTU/LBMOL-R            -29.2512
  BTU/LB-R                -1.7466
DENSITY:
  LBMOL/CUFT               0.1583
  LB/CUFT                  2.6514
AVG MW                    16.7476

NG4
---

STREAM ID                 NG4
FROM :                    PHX3
TO   :                    CHX1

SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  METHA-01              7.8643+04
  ETHAN-01              2470.4681
  PROPA-01               823.4894
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              8.1937+04
  LB/HR                 1.3723+06
  CUFT/HR               4.1299+05
STATE VARIABLES:
  TEMP   F               -29.0000
  PRES   PSIA            720.0000
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -3.3833+04
  BTU/LB               -2020.1734
  BTU/HR               -2.7722+09
ENTROPY:
  BTU/LBMOL-R            -30.6739
  BTU/LB-R                -1.8315
DENSITY:
  LBMOL/CUFT               0.1984
  LB/CUFT                  3.3227
AVG MW                    16.7476

NG5
```

```
---

STREAM ID                NG5
FROM :                   CHX1
TO   :                   CHX2

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  METHA-01             7.8643+04
  ETHAN-01             2470.4681
  PROPA-01              823.4894
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR             8.1937+04
  LB/HR                1.3723+06
  CUFT/HR              6.2024+04
STATE VARIABLES:
  TEMP   F             -170.0000
  PRES   PSIA           720.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -3.7518+04
  BTU/LB              -2240.1926
  BTU/HR              -3.0741+09
ENTROPY:
  BTU/LBMOL-R           -41.1187
  BTU/LB-R               -2.4552
DENSITY:
  LBMOL/CUFT              1.3211
  LB/CUFT                22.1246
AVG MW                   16.7476

NG6
---

STREAM ID                NG6
FROM :                   CHX2
TO   :                   V7

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  METHA-01             7.8643+04
  ETHAN-01             2470.4681
  PROPA-01              823.4894
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR             8.1937+04
  LB/HR                1.3723+06
```

```
  CUFT/HR               4.8615+04
STATE VARIABLES:
  TEMP   F             -262.0000
  PRES   PSIA           720.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL            -3.8899+04
  BTU/LB               -2322.6349
  BTU/HR               -3.1872+09
ENTROPY:
  BTU/LBMOL-R           -46.8211
  BTU/LB-R               -2.7957
DENSITY:
  LBMOL/CUFT              1.6854
  LB/CUFT                28.2267
AVG MW                   16.7476

NG7
---

STREAM ID                NG7
FROM :                   V7
TO   :                   ----

SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  METHA-01              7.8643+04
  ETHAN-01              2470.4681
  PROPA-01               823.4894
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR              8.1937+04
  LB/HR                 1.3723+06
  CUFT/HR               4.9436+04
STATE VARIABLES:
  TEMP   F             -258.7708
  PRES   PSIA            75.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL            -3.8899+04
  BTU/LB               -2322.6349
  BTU/HR               -3.1872+09
ENTROPY:
  BTU/LBMOL-R           -46.4549
  BTU/LB-R               -2.7738
DENSITY:
  LBMOL/CUFT              1.6574
```

```
  LB/CUFT                   27.7583
AVG MW                      16.7476

P1
--

STREAM ID                   P1
FROM :                      C5
TO   :                      PHT

SUBSTREAM: MIXED
PHASE:                      VAPOR
COMPONENTS: LBMOL/HR
  METHA-01                    0.0
  ETHAN-01                    0.0
  PROPA-01                 1.4274+05
  N2                          0.0
TOTAL FLOW:
  LBMOL/HR                 1.4274+05
  LB/HR                    6.2943+06
  CUFT/HR                  3.8639+06
STATE VARIABLES:
  TEMP   F                  146.7917
  PRES   PSIA               200.0000
  VFRAC                       1.0000
  LFRAC                       0.0
  SFRAC                       0.0
ENTHALPY:
  BTU/LBMOL               -4.4341+04
  BTU/LB                  -1005.5409
  BTU/HR                  -6.3291+09
ENTROPY:
  BTU/LBMOL-R               -67.9689
  BTU/LB-R                   -1.5414
DENSITY:
  LBMOL/CUFT               3.6941-02
  LB/CUFT                     1.6290
AVG MW                      44.0965

P2
--

STREAM ID                   P2
FROM :                      PHT
TO   :                      V1

SUBSTREAM: MIXED
PHASE:                      LIQUID
COMPONENTS: LBMOL/HR
  METHA-01                    0.0
  ETHAN-01                    0.0
  PROPA-01                 1.4274+05
```

```
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              1.4274+05
  LB/HR                 6.2943+06
  CUFT/HR               2.2437+05
STATE VARIABLES:
  TEMP   F               100.0000
  PRES   PSIA            195.0000
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -5.1274+04
  BTU/LB               -1162.7575
  BTU/HR               -7.3187+09
ENTROPY:
  BTU/LBMOL-R            -80.2144
  BTU/LB-R                -1.8191
DENSITY:
  LBMOL/CUFT               0.6362
  LB/CUFT                 28.0532
AVG MW                    44.0965

P3
--

STREAM ID                P3
FROM :                   V1
TO   :                   PHX1

SUBSTREAM: MIXED
PHASE:                    MIXED
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01              1.4274+05
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              1.4274+05
  LB/HR                 6.2943+06
  CUFT/HR               1.1568+06
STATE VARIABLES:
  TEMP   F                63.8804
  PRES   PSIA            115.0000
  VFRAC                    0.1660
  LFRAC                    0.8340
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -5.1274+04
  BTU/LB               -1162.7575
  BTU/HR               -7.3187+09
ENTROPY:
```

```
  BTU/LBMOL-R          -80.0998
  BTU/LB-R              -1.8165
DENSITY:
  LBMOL/CUFT             0.1234
  LB/CUFT                5.4410
AVG MW                  44.0965

P4
--

STREAM ID               P4
FROM :                  PHX1
TO   :                  F1

SUBSTREAM: MIXED
PHASE:                  MIXED
COMPONENTS: LBMOL/HR
  METHA-01               0.0
  ETHAN-01               0.0
  PROPA-01             1.4274+05
  N2                     0.0
TOTAL FLOW:
  LBMOL/HR             1.4274+05
  LB/HR                6.2943+06
  CUFT/HR              1.3418+06
STATE VARIABLES:
  TEMP   F              63.8804
  PRES   PSIA          115.0000
  VFRAC                  0.1982
  LFRAC                  0.8018
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL           -5.1057+04
  BTU/LB              -1157.8481
  BTU/HR              -7.2878+09
ENTROPY:
  BTU/LBMOL-R          -79.6863
  BTU/LB-R              -1.8071
DENSITY:
  LBMOL/CUFT             0.1064
  LB/CUFT                4.6908
AVG MW                  44.0965

P5
--

STREAM ID               P5
FROM :                  F1
TO   :                  C5

SUBSTREAM: MIXED
PHASE:                  VAPOR
```

```
COMPONENTS: LBMOL/HR
  METHA-01              0.0
  ETHAN-01              0.0
  PROPA-01           7.1369+04
  N2                    0.0
TOTAL FLOW:
  LBMOL/HR           7.1369+04
  LB/HR              3.1471+06
  CUFT/HR            2.9703+06
STATE VARIABLES:
  TEMP   F             63.8804
  PRES   PSIA         115.0000
  VFRAC                 1.0000
  LFRAC                 0.0
  SFRAC                 0.0
ENTHALPY:
  BTU/LBMOL         -4.5676+04
  BTU/LB            -1035.8204
  BTU/HR            -3.2599+09
ENTROPY:
  BTU/LBMOL-R         -69.4084
  BTU/LB-R             -1.5740
DENSITY:
  LBMOL/CUFT         2.4027-02
  LB/CUFT               1.0595
AVG MW                 44.0965

P6
--

STREAM ID              P6
FROM :                 F1
TO   :                 SPLIT

SUBSTREAM: MIXED
PHASE:                 LIQUID
COMPONENTS: LBMOL/HR
  METHA-01              0.0
  ETHAN-01              0.0
  PROPA-01           7.1369+04
  N2                    0.0
TOTAL FLOW:
  LBMOL/HR           7.1369+04
  LB/HR              3.1471+06
  CUFT/HR            1.0245+05
STATE VARIABLES:
  TEMP   F             63.8804
  PRES   PSIA         115.0000
  VFRAC                 0.0
  LFRAC                 1.0000
  SFRAC                 0.0
ENTHALPY:
```

```
  BTU/LBMOL          -5.2387+04
  BTU/LB             -1188.0161
  BTU/HR             -3.7388+09
ENTROPY:
  BTU/LBMOL-R          -82.2272
  BTU/LB-R              -1.8647
DENSITY:
  LBMOL/CUFT             0.6966
  LB/CUFT               30.7184
AVG MW                  44.0965

P7
--

STREAM ID               P7
FROM :                  SPLIT
TO   :                  V2

SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  METHA-01               0.0
  ETHAN-01               0.0
  PROPA-01            1.0705+04
  N2                     0.0
TOTAL FLOW:
  LBMOL/HR            1.0705+04
  LB/HR               4.7207+05
  CUFT/HR             1.5368+04
STATE VARIABLES:
  TEMP   F              63.8804
  PRES   PSIA          115.0000
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -5.2387+04
  BTU/LB             -1188.0161
  BTU/HR             -5.6083+08
ENTROPY:
  BTU/LBMOL-R          -82.2272
  BTU/LB-R              -1.8647
DENSITY:
  LBMOL/CUFT             0.6966
  LB/CUFT               30.7184
AVG MW                  44.0965

P8
--

STREAM ID               P8
FROM :                  V2
```

```
TO   :                  PHX2

SUBSTREAM: MIXED
PHASE:                  MIXED
COMPONENTS: LBMOL/HR
  METHA-01                0.0
  ETHAN-01                0.0
  PROPA-01              1.0705+04
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR              1.0705+04
  LB/HR                 4.7207+05
  CUFT/HR               1.3581+05
STATE VARIABLES:
  TEMP   F                24.9692
  PRES   PSIA             61.0000
  VFRAC                   0.1494
  LFRAC                   0.8506
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL            -5.2387+04
  BTU/LB               -1188.0161
  BTU/HR               -5.6083+08
ENTROPY:
  BTU/LBMOL-R            -82.1107
  BTU/LB-R                -1.8621
DENSITY:
  LBMOL/CUFT            7.8828-02
  LB/CUFT                 3.4760
AVG MW                    44.0965

P9
--

STREAM ID               P9
FROM :                  PHX2
TO   :                  F2

SUBSTREAM: MIXED
PHASE:                  MIXED
COMPONENTS: LBMOL/HR
  METHA-01                0.0
  ETHAN-01                0.0
  PROPA-01              1.0705+04
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR              1.0705+04
  LB/HR                 4.7207+05
  CUFT/HR               4.8792+05
STATE VARIABLES:
  TEMP   F                24.9692
  PRES   PSIA             61.0000
```

```
  VFRAC                    0.5822
  LFRAC                    0.4178
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -4.9208+04
  BTU/LB               -1115.9159
  BTU/HR               -5.2679+08
ENTROPY:
  BTU/LBMOL-R            -75.5505
  BTU/LB-R                -1.7133
DENSITY:
  LBMOL/CUFT            2.1941-02
  LB/CUFT                  0.9675
AVG MW                    44.0965

P10
---

STREAM ID                 P10
FROM :                    F2
TO   :                    C4

SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01              3211.6085
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              3211.6085
  LB/HR                 1.4162+05
  CUFT/HR               2.4835+05
STATE VARIABLES:
  TEMP   F                24.9692
  PRES   PSIA             61.0000
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -4.6139+04
  BTU/LB               -1046.3156
  BTU/HR               -1.4818+08
ENTROPY:
  BTU/LBMOL-R            -69.2177
  BTU/LB-R                -1.5697
DENSITY:
  LBMOL/CUFT            1.2932-02
  LB/CUFT                  0.5702
AVG MW                    44.0965

P11
```

```
---

STREAM ID                 P11
FROM :                    F2
TO   :                    V3

SUBSTREAM: MIXED
PHASE:                    LIQUID
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01              7493.7532
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              7493.7532
  LB/HR                 3.3045+05
  CUFT/HR               9960.6738
STATE VARIABLES:
  TEMP   F                24.9692
  PRES   PSIA             61.0000
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -5.3485+04
  BTU/LB               -1212.9107
  BTU/HR               -4.0080+08
ENTROPY:
  BTU/LBMOL-R            -84.3759
  BTU/LB-R                -1.9134
DENSITY:
  LBMOL/CUFT               0.7523
  LB/CUFT                 33.1753
AVG MW                    44.0965

P12
---

STREAM ID                 P12
FROM :                    V3
TO   :                    PHX3

SUBSTREAM: MIXED
PHASE:                    MIXED
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01              7493.7532
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              7493.7532
  LB/HR                 3.3045+05
```

```
  CUFT/HR                3.5532+05
STATE VARIABLES:
  TEMP   F               -34.7916
  PRES   PSIA             18.0000
  VFRAC                    0.1904
  LFRAC                    0.8096
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL             -5.3485+04
  BTU/LB                -1212.9107
  BTU/HR                -4.0080+08
ENTROPY:
  BTU/LBMOL-R            -84.1151
  BTU/LB-R                -1.9075
DENSITY:
  LBMOL/CUFT             2.1090-02
  LB/CUFT                  0.9300
AVG MW                    44.0965

P13
---

STREAM ID                 P13
FROM :                    PHX3
TO   :                    C3

SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01               7493.7532
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR               7493.7532
  LB/HR                  3.3045+05
  CUFT/HR                2.0152+06
STATE VARIABLES:
  TEMP   F                 4.9351
  PRES   PSIA             18.0000
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL             -4.6289+04
  BTU/LB                -1049.7191
  BTU/HR                -3.4688+08
ENTROPY:
  BTU/LBMOL-R            -67.2444
  BTU/LB-R                -1.5249
DENSITY:
  LBMOL/CUFT             3.7186-03
```

```
  LB/CUFT                  0.1640
AVG MW                    44.0965

P14
---

STREAM ID                 P14
FROM :                    C3
TO   :                    C4

SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01              4.9958+04
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              4.9958+04
  LB/HR                 2.2030+06
  CUFT/HR               4.6587+06
STATE VARIABLES:
  TEMP   F               103.4186
  PRES   PSIA             61.0000
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -4.4724+04
  BTU/LB               -1014.2231
  BTU/HR               -2.2343+09
ENTROPY:
  BTU/LBMOL-R            -66.5139
  BTU/LB-R                -1.5084
DENSITY:
  LBMOL/CUFT            1.0724-02
  LB/CUFT                  0.4729
AVG MW                    44.0965

P15
---

STREAM ID                 P15
FROM :                    C4
TO   :                    C5

SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01              7.1369+04
```

```
  N2                     0.0
TOTAL FLOW:
  LBMOL/HR            7.1369+04
  LB/HR               3.1471+06
  CUFT/HR             3.5529+06
STATE VARIABLES:
  TEMP   F             132.0367
  PRES   PSIA          115.0000
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -4.4348+04
  BTU/LB             -1005.6998
  BTU/HR             -3.1651+09
ENTROPY:
  BTU/LBMOL-R          -67.0249
  BTU/LB-R              -1.5200
DENSITY:
  LBMOL/CUFT          2.0087-02
  LB/CUFT                0.8858
AVG MW                  44.0965

P16
---

STREAM ID               P16
FROM :                  SPLIT
TO   :                  V4

SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  METHA-01               0.0
  ETHAN-01               0.0
  PROPA-01            6.0664+04
  N2                     0.0
TOTAL FLOW:
  LBMOL/HR            6.0664+04
  LB/HR               2.6751+06
  CUFT/HR             8.7083+04
STATE VARIABLES:
  TEMP   F              63.8804
  PRES   PSIA          115.0000
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -5.2387+04
  BTU/LB             -1188.0161
  BTU/HR             -3.1780+09
ENTROPY:
```

```
  BTU/LBMOL-R           -82.2272
  BTU/LB-R               -1.8647
DENSITY:
  LBMOL/CUFT              0.6966
  LB/CUFT                30.7184
AVG MW                   44.0965

P17
---

STREAM ID                P17
FROM :                   V4
TO   :                   MHX1

SUBSTREAM: MIXED
PHASE:                   MIXED
COMPONENTS: LBMOL/HR
  METHA-01                0.0
  ETHAN-01                0.0
  PROPA-01              6.0664+04
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR              6.0664+04
  LB/HR                 2.6751+06
  CUFT/HR               7.6957+05
STATE VARIABLES:
  TEMP   F               24.9692
  PRES   PSIA            61.0000
  VFRAC                   0.1494
  LFRAC                   0.8506
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL            -5.2387+04
  BTU/LB               -1188.0161
  BTU/HR               -3.1780+09
ENTROPY:
  BTU/LBMOL-R           -82.1107
  BTU/LB-R               -1.8621
DENSITY:
  LBMOL/CUFT            7.8828-02
  LB/CUFT                 3.4760
AVG MW                   44.0965

P18
---

STREAM ID                P18
FROM :                   MHX1
TO   :                   F3

SUBSTREAM: MIXED
PHASE:                   MIXED
```

```
COMPONENTS: LBMOL/HR
  METHA-01              0.0
  ETHAN-01              0.0
  PROPA-01          6.0664+04
  N2                    0.0
TOTAL FLOW:
  LBMOL/HR          6.0664+04
  LB/HR             2.6751+06
  CUFT/HR           1.7202+06
STATE VARIABLES:
  TEMP   F            24.9692
  PRES   PSIA         61.0000
  VFRAC                0.3556
  LFRAC                0.6444
  SFRAC                0.0
ENTHALPY:
  BTU/LBMOL        -5.0873+04
  BTU/LB           -1153.6672
  BTU/HR           -3.0861+09
ENTROPY:
  BTU/LBMOL-R        -78.9854
  BTU/LB-R            -1.7912
DENSITY:
  LBMOL/CUFT        3.5266-02
  LB/CUFT              1.5551
AVG MW                44.0965

P19
---

STREAM ID             P19
FROM :                F3
TO   :                C4

SUBSTREAM: MIXED
PHASE:                VAPOR
COMPONENTS: LBMOL/HR
  METHA-01              0.0
  ETHAN-01              0.0
  PROPA-01          1.8199+04
  N2                    0.0
TOTAL FLOW:
  LBMOL/HR          1.8199+04
  LB/HR             8.0252+05
  CUFT/HR           1.4073+06
STATE VARIABLES:
  TEMP   F            24.9692
  PRES   PSIA         61.0000
  VFRAC                1.0000
  LFRAC                0.0
  SFRAC                0.0
ENTHALPY:
```

```
  BTU/LBMOL           -4.6139+04
  BTU/LB              -1046.3156
  BTU/HR              -8.3969+08
ENTROPY:
  BTU/LBMOL-R           -69.2177
  BTU/LB-R               -1.5697
DENSITY:
  LBMOL/CUFT          1.2932-02
  LB/CUFT                0.5702
AVG MW                  44.0965

P20
---

STREAM ID               P20
FROM :                  F3
TO   :                  V5

SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  METHA-01                0.0
  ETHAN-01                0.0
  PROPA-01            4.2465+04
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR            4.2465+04
  LB/HR               1.8725+06
  CUFT/HR             5.6444+04
STATE VARIABLES:
  TEMP   F              24.9692
  PRES   PSIA           61.0000
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -5.3485+04
  BTU/LB              -1212.9107
  BTU/HR              -2.2712+09
ENTROPY:
  BTU/LBMOL-R           -84.3759
  BTU/LB-R               -1.9134
DENSITY:
  LBMOL/CUFT              0.7523
  LB/CUFT               33.1753
AVG MW                  44.0965

P21
---

STREAM ID               P21
FROM :                  V5
```

```
TO   :                    MHX2

SUBSTREAM: MIXED
PHASE:                    MIXED
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01               4.2465+04
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR               4.2465+04
  LB/HR                  1.8725+06
  CUFT/HR                2.0135+06
STATE VARIABLES:
  TEMP   F                -34.7916
  PRES   PSIA              18.0000
  VFRAC                     0.1904
  LFRAC                     0.8096
  SFRAC                     0.0
ENTHALPY:
  BTU/LBMOL             -5.3485+04
  BTU/LB                -1212.9107
  BTU/HR                -2.2712+09
ENTROPY:
  BTU/LBMOL-R             -84.1151
  BTU/LB-R                 -1.9075
DENSITY:
  LBMOL/CUFT             2.1090-02
  LB/CUFT                   0.9300
AVG MW                     44.0965

P22
---

STREAM ID                 P22
FROM :                    MHX2
TO   :                    F4

SUBSTREAM: MIXED
PHASE:                    MIXED
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01               4.2465+04
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR               4.2465+04
  LB/HR                  1.8725+06
  CUFT/HR                9.6352+06
STATE VARIABLES:
  TEMP   F                -34.7916
  PRES   PSIA              18.0000
```

```
  VFRAC                   0.9302
  LFRAC                6.9803-02
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -4.7490+04
  BTU/LB              -1076.9640
  BTU/HR              -2.0167+09
ENTROPY:
  BTU/LBMOL-R           -70.0057
  BTU/LB-R               -1.5876
DENSITY:
  LBMOL/CUFT           4.4072-03
  LB/CUFT                 0.1943
AVG MW                   44.0965

P23
---

STREAM ID                P23
FROM :                   F4
TO   :                   C3

SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  METHA-01                0.0
  ETHAN-01                0.0
  PROPA-01             1.2739+04
  N2                      0.0
TOTAL FLOW:
  LBMOL/HR             1.2739+04
  LB/HR                5.6176+05
  CUFT/HR              3.1063+06
STATE VARIABLES:
  TEMP   F              -34.7916
  PRES   PSIA            18.0000
  VFRAC                   1.0000
  LFRAC                   0.0
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -4.6925+04
  BTU/LB              -1064.1364
  BTU/HR              -5.9779+08
ENTROPY:
  BTU/LBMOL-R           -68.6744
  BTU/LB-R               -1.5574
DENSITY:
  LBMOL/CUFT           4.1011-03
  LB/CUFT                 0.1808
AVG MW                   44.0965

P24
```

STREAM ID	P24
FROM :	F4
TO :	V6
SUBSTREAM: MIXED	
PHASE:	LIQUID
COMPONENTS: LBMOL/HR	
METHA-01	0.0
ETHAN-01	0.0
PROPA-01	2.9725+04
N2	0.0
TOTAL FLOW:	
LBMOL/HR	2.9725+04
LB/HR	1.3108+06
CUFT/HR	3.6083+04
STATE VARIABLES:	
TEMP F	-34.7916
PRES PSIA	18.0000
VFRAC	0.0
LFRAC	1.0000
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-5.5028+04
BTU/LB	-1247.9054
BTU/HR	-1.6357+09
ENTROPY:	
BTU/LBMOL-R	-87.7471
BTU/LB-R	-1.9899
DENSITY:	
LBMOL/CUFT	0.8238
LB/CUFT	36.3270
AVG MW	44.0965

P25

STREAM ID	P25
FROM :	V6
TO :	MHX3
SUBSTREAM: MIXED	
PHASE:	MIXED
COMPONENTS: LBMOL/HR	
METHA-01	0.0
ETHAN-01	0.0
PROPA-01	2.9725+04
N2	0.0
TOTAL FLOW:	
LBMOL/HR	2.9725+04
LB/HR	1.3108+06

```
  CUFT/HR               4.4490+06
STATE VARIABLES:
  TEMP   F               -89.3490
  PRES   PSIA              4.0000
  VFRAC                    0.1514
  LFRAC                    0.8486
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL             -5.5028+04
  BTU/LB                -1247.9054
  BTU/HR                -1.6357+09
ENTROPY:
  BTU/LBMOL-R            -87.4993
  BTU/LB-R                -1.9843
DENSITY:
  LBMOL/CUFT            6.6813-03
  LB/CUFT                  0.2946
AVG MW                    44.0965

P26
---

STREAM ID                 P26
FROM :                    MHX3
TO   :                    C2

SUBSTREAM: MIXED
PHASE:                    VAPOR
COMPONENTS: LBMOL/HR
  METHA-01                 0.0
  ETHAN-01                 0.0
  PROPA-01              2.9725+04
  N2                       0.0
TOTAL FLOW:
  LBMOL/HR              2.9725+04
  LB/HR                 1.3108+06
  CUFT/HR               3.0761+07
STATE VARIABLES:
  TEMP   F               -69.9731
  PRES   PSIA              4.0000
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL             -4.7395+04
  BTU/LB                -1074.8019
  BTU/HR                -1.4088+09
ENTROPY:
  BTU/LBMOL-R            -66.9065
  BTU/LB-R                -1.5173
DENSITY:
  LBMOL/CUFT            9.6633-04
```

LB/CUFT	4.2612-02
AVG MW	44.0965

P27

STREAM ID	P27
FROM :	C2
TO :	C3
SUBSTREAM: MIXED	
PHASE:	VAPOR
COMPONENTS: LBMOL/HR	
METHA-01	0.0
ETHAN-01	0.0
PROPA-01	2.9725+04
N2	0.0
TOTAL FLOW:	
LBMOL/HR	2.9725+04
LB/HR	1.3108+06
CUFT/HR	8.5047+06
STATE VARIABLES:	
TEMP F	32.4193
PRES PSIA	18.0000
VFRAC	1.0000
LFRAC	0.0
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-4.5834+04
BTU/LB	-1039.3956
BTU/HR	-1.3624+09
ENTROPY:	
BTU/LBMOL-R	-66.2925
BTU/LB-R	-1.5034
DENSITY:	
LBMOL/CUFT	3.4951-03
LB/CUFT	0.1541
AVG MW	44.0965

Appendix C: Example Design Calculations

Example Heat Exchanger Calculation (PHX1)[20]

The ASPEN block report for PHX1 provides the following heat duty:

Q (BTU/hr) =30,900,953.41

U (BTU/hr ft^2 °F) = 50

$T_{hot\ in}$ = 107°F

$T_{hot\ out}$ = 70°F

$T_{cold\ in}$ = 63.88°F

$T_{cold\ out}$ = 63.88°F

The surface area of a heat exchanger can be calculated using the following equation:

$$Q = UAF_T\Delta T_{LM}$$

$$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{(107°\text{F} - 63.88\ °\text{F}) - (70\ °\text{F} - 63.88\ °\text{F})}{\ln\left(\frac{(107°\text{F} - 63.88\ °\text{F})}{(70\ °\text{F} - 63.88\ °\text{F})}\right)} = 18.95°\text{F}$$

F_T = 1 (Due to isothermal nature of shell side stream)

$$A = \frac{Q}{UF_T\Delta T_{LM}} = \frac{30{,}900{,}953.41\ \text{BTU/hr}}{(50\ \text{BTU/hr ft}^2\ °\text{F})(1)(18.95°\text{F})} = 32{,}679.42\ \text{ft}^2$$

[20] Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 3rd ed. Hoboken, NJ: John Wiley & Sons, Inc., 2004. Print.

Heat Exchanger Costing

$C_B = \exp\{11.967 - 0.8709[ln(A)] + 0.09005[\ln(A)]^2\}$

$= \exp\{11.967 - 0.8709[ln(32{,}679.42\ )] + 0.09005[\ln(32{,}679.42\ )]^2\}$ = \$115,007.23

$F_P = 0.9803 + 0.018\left(\frac{P}{100}\right) + 0.0017(\frac{P}{100})^2$

$= 0.9803 + 0.018\left(\frac{115}{100}\right) + 0.0017(\frac{115}{100})^2$ = 1.0032

$F_M = 1$ (Shell and tube constructed from steel carbon)

$F_L = 1$ (20 ft. tube length)

$C_P = F_P F_M F_L C_B = (1.0032)(1)(1)(\$115{,}007.23)$ = \$310,886.37

The bare module cost of a heat exchanger can be calculated using the following equation:

$$C_{BM} = C_P\left(\frac{I}{I_b}\right)[F_{BM} + (F_d F_P F_m - 1)]$$

I = 566.4 (2013 CE Index)

I_b = 500 (2006 CE Index)

$F_{BM} = 3.17$ (Shell and tube heat exchanger, Table 22.11 Seider et al.)

F_d = Assumed to be 1

$C_{BM} = \$310{,}886.37\left(\frac{560}{500}\right)[3.17 + ((1)(1.0032)(1) - 1)]$ = \$1,117,529.42

Example Compressor Calculation (C1)

The price of the compressor is determined by the equation:

$$C_P = F_D F_M C_B$$

where F_D is the drive factor, F_M is the material factor, and C_B is the base purchase cost.

$F_D = 1$

$F_M = 1$

$C_B = \exp(7.58 + 0.8 * ln(P))$

$P = 9{,}120\ hp$

$C_B = \exp(7.58 + 0.8 * ln(9{,}120)) = \$2{,}883{,}652$

$C_P = (1)(1)(\$2{,}883{,}652) = \$2{,}883{,}652$

The bare module cost is determined by the following equation:

$$C_{BM} = C_P \left(\frac{I}{I_b}\right) [F_{BM} + (F_d F_P F_m - 1)]$$

where I is the current cost index, I_b is the 2006 cost index, F_{BM} is the bare module factor, and F_d is the equipment design factor.

I = 566.4 (2013 CE Index)

I_b = 500 (2006 CE Index)

F_{BM} = 2.15 (Gas compressors and drivers, Table 22.11 Seider et al.)

F_d = Assumed to be 1

$F_p = 1$

$C_{BM} = \$2{,}883{,}652 \left(\frac{566.4}{500}\right) \left[2.15 + \left((1)(1)(1) - 1\right)\right] = \$7{,}023{,}192$

Example Turbine Calculation (T1)

The price of the liquid inlet turbine is determined by the equation:

$$C_P = 1400 * P^{0.70}$$

where P is the power produced.

$P = 2{,}764\ hp$

$C_P = 1400 * (2{,}764)^{0.70} = \$359{,}055$

The bare module cost is determined by the following equation:

$$C_{BM} = C_P \left(\frac{I}{I_b}\right) [F_{BM} + (F_d F_P F_m - 1)]$$

where I is the current cost index, I_b is the 2006 cost index, F_{BM} is the bare module factor, and F_d is the equipment design factor.

I = 566.4 (2013 CE Index)

I_b = 500 (2006 CE Index)

F_{BM} = 2.15 (Gas compressors and drivers, Table 22.11 Seider et al.)

F_d = Assumed to be 1

$F_p = 1$

$$C_{BM} = \$359{,}055 \left(\frac{566.4}{500}\right) \left[2.15 + \left((1)(1)(1) - 1\right)\right] = \$874{,}485$$

Example Pump Power Calculation

The power consumption for the pump's electric motor is determined by the following equation:

$$P_C = \frac{P_B}{\eta_M}$$

where P_B is the pump brake horsepower and η_M is the fractional efficiency of the electric motor.

$$P_B = \frac{QH\rho}{33{,}000\eta_P}$$

where Q is the flow rate through the pump, H is the pump head, ρ is the liquid density, and η_P is the fractional efficiency of the pump.

$Q = 5{,}000\ gallons\ per\ minute\ (gpm)$

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

$\Delta P = 7\ psia$

$\rho = 62.3\ lb/ft^3$

$H = \frac{7\ psia}{62.3\ lb/ft^3} = 16.17\ ft$

$\eta_P = -0.316 + 0.24015 * \ln(Q) - 0.01199 * (\ln(Q))\text{^}2$

$\eta_P = -0.316 + 0.24015 * \ln(5000) - 0.01199 * (\ln(5000))^2 = 0.86$

$P_B = \frac{(5{,}000)(16.17)(62.3)}{(33{,}000)(0.86)} = 23.75\ hp$

$\eta_M = 0.8 + 0.0319 * \ln(P_B) - 0.00182 * (\ln(P_B))^2$

$\eta_M = 0.8 + 0.0319 * \ln(23.75) - 0.00182 * (\ln(23.75))^2 = 0.88$

$P_C = \frac{23.75}{0.88} = 26.9$

$P_{C,total} = N * P_C$

$N = 31.9\ divisions$

$$P_{C,total} = 31.9 * 26.9 = 858\ hp$$

<u>Example Cooling Water Calculation (MHT2)</u>

Cooling Water Temperature In: 65°F

Cooling Water Temperature Out: 79°F

The ASPEN block report for MHT2 provides the following heat duty:

Q (BTU/hr) = 260,722,140

Specific Enthalpy Water at 65°F (BTU/lb): -6907.283

Specific Enthalpy Water at 79°F (BTU/lb): -6891.165

$$Q = \dot{m}\left(\widehat{H}_{out} - \widehat{H}_{in}\right)$$

$$\dot{m} = \frac{Q}{(\widehat{H}_{out} - \widehat{H}_{in})} = \frac{260722140\,\frac{\text{BTU}}{\text{hr}}}{-6891.17\,\frac{\text{BTU}}{\text{lb}} - \left(-6907.28\,\frac{\text{BTU}}{\text{lb}}\right)} = 16176300\,\frac{lb}{hr}$$

Density of water at this temperature was found to be 60.35 $\frac{lb}{ft^3}$

$$16176300\,\frac{\text{lb}}{\text{hr}} \times \frac{1}{60.35\,\frac{\text{lb}}{\text{ft}^3}} \times 7.48\,\frac{\text{gal}}{\text{ft}^3} \times \frac{1}{60\,\frac{\text{min}}{\text{hr}}} = 33{,}420 \text{ gpm}$$

While the cost of this water is assumed to be free, this information is used to calculate the total load for pumps and corresponding electricity charge.

Appendix D: Economic Analysis Results

General Information

Process Title:	**Marcellus Shale Gas Export**
Product:	**LNG**
Plant Site Location:	**Lusby, Maryland**
Site Factor:	**1.10**
Operating Hours per Year:	**8234**
Operating Days Per Year:	**343**
Operating Factor:	**0.9400**

Product Information

This Process will Yield

681	ton of LNG per hour
16,351	ton of LNG per day
5,610,000	ton of LNG per year

Price **$800.00** **/ton**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2013	Design		0.0%		
2014	Construction	100%	0.0%		
2015	Construction	0%	0.0%		
2016	Construction	0%	0.0%		
2017	Construction	0%	0.0%		
2018	Production		45.0%	20.00%	$800.00
2019	Production		67.5%	32.00%	$800.00
2020	Production		90.0%	19.20%	$800.00
2021	Production		90.0%	11.52%	$800.00
2022	Production		90.0%	11.52%	$800.00
2023	Production		90.0%	5.76%	$800.00
2024	Production		90.0%		$800.00
2025	Production		90.0%		$800.00
2026	Production		90.0%		$800.00
2027	Production		90.0%		$800.00
2028	Production		90.0%		$800.00
2029	Production		90.0%		$800.00
2030	Production		90.0%		$800.00
2031	Production		90.0%		$800.00
2032	Production		90.0%		$800.00
2033	Production		90.0%		$800.00
2034	Production		90.0%		$800.00
2035	Production		90.0%		$800.00
2036	Production		90.0%		$800.00
2037	Production		90.0%		$800.00
2038	Production		90.0%		$800.00

Equipment Costs

Equipment Description		Bare Module Cost
C1	Fabricated Equipment	$7,023,192
C2	Fabricated Equipment	$10,064,275
C3	Fabricated Equipment	$8,292,772
C4	Fabricated Equipment	$12,540,566
C5	Fabricated Equipment	$34,945,878
C6	Fabricated Equipment	$16,007,991
T1	Fabricated Equipment	$874,485
T2	Fabricated Equipment	$531,720
PHX1	Fabricated Equipment	$414,754
PHX2	Fabricated Equipment	$460,777
PHX3	Fabricated Equipment	$541,258
MHX1	Fabricated Equipment	$400,574
MHX2	Fabricated Equipment	$846,271
MHX3	Fabricated Equipment	$649,158
MHT1	Fabricated Equipment	$120,072
MHT2	Fabricated Equipment	$528,124
PHT1	Fabricated Equipment	$5,626,876
CHX1	Fabricated Equipment	$80,299,293
CHX2	Fabricated Equipment	$11,964,584
PreTreatment	Fabricated Equipment	$9,606,631
Total		***$201,739,249***

Raw Materials

	Raw Material:	Unit:	Required Ratio: (per unit of product)	Cost of Raw Material:
1	Propane	gallon	0 gallon per ton of LNG	$1.880 per gallon
2	Methane	mmbtu	0 mmbtu per ton of LNG	$5.00 per mmbtu
3	Ethane	gallon	0 gallon per ton of LNG	$0.25 per gallon
4	Nitrogen	cubic feet	0 cubic feet per ton of LNG	$20.00 per cubic feet
	Total Weighted Average:			$0.000E+00 per ton of LNG

Byproducts

	Byproduct:	Unit:	Ratio to Product	Byproduct Selling Price
	Total Weighted Average:			$0.000E+00 per ton of LNG

Utilities

	Utility:	Unit:	Required Ratio	Utility Cost
1	High Pressure Steam	lb	0 lb per ton of LNG	$0.000E+00 per lb
2	Low Pressure Steam	lb	0 lb per ton of LNG	$0.000E+00 per lb
3	Process Water	gal	0 gal per ton of LNG	$0.000E+00 per gal
4	Cooling Water	gal	0 gal per ton of LNG	$75.000 per gal
5	Electricity	kWh	151.09197 kWh per ton of LNG	$0.082 per kWh
	Total Weighted Average:			$12.390 per ton of LNG

Variable Costs

General Expenses:

Selling / Transfer Expenses:	**3.00%**	**of Sales**
Direct Research:	**0.00%**	**of Sales**
Allocated Research:	**0.00%**	**of Sales**
Administrative Expense:	**2.00%**	**of Sales**
Management Incentive Compensation:	**1.25%**	**of Sales**

Working Capital

Accounts Receivable	⇨	**30**	**Days**
Cash Reserves (excluding Raw Materials)	⇨	**30**	**Days**
Accounts Payable	⇨	**30**	**Days**
LNG Inventory	⇨	**4**	**Days**
Raw Materials	⇨	**2**	**Days**

Appendix E: Material Safety Data Sheets (MSDS)

Material Safety Data Sheet

Airgas

Methane

Section 1. Chemical product and company identification

Product name	:	Methane
Supplier	:	AIRGAS INC., on behalf of its subsidiaries 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
Product use	:	Synthetic/Analytical chemistry.
Synonym	:	fire damp; marsh gas; methane (dot); methyl hydride
MSDS #	:	001033
Date of Preparation/Revision	:	**4/1/2013.**
In case of emergency	:	1-866-734-3438

Section 2. Hazards identification

Physical state	:	Gas. [COLORLESS GAS; MAY BE A LIQUID UNDER PRESSURE OR REFRIGERATION.]
Emergency overview	:	WARNING! GAS: CONTENTS UNDER PRESURE. Extremely flammable. May cause flash fire. Do not puncture or incinerate container. Can cause rapid suffocation. May cause severe frostbite. LIQUID: Extremely flammable. Extremely cold liquid and gas under pressure. Can cause rapid suffocation. May cause severe frostbite. Keep away from heat, sparks and flame. Do not puncture or incinerate container. Use only with adequate ventilation. Keep container closed. Contact with rapidly expanding gases or liquids can cause frostbite.
Routes of entry	:	Inhalation
Potential acute health effects		
Eyes	:	Contact with rapidly expanding gas may cause burns or frostbite. Contact with cryogenic liquid can cause frostbite and cryogenic burns.
Skin	:	Contact with rapidly expanding gas may cause burns or frostbite. Contact with cryogenic liquid can cause frostbite and cryogenic burns.
Inhalation	:	Acts as a simple asphyxiant.
Ingestion	:	Ingestion is not a normal route of exposure for gases. Contact with cryogenic liquid can cause frostbite and cryogenic burns.
Medical conditions aggravated by over-exposure	:	Acute or chronic respiratory conditions may be aggravated by overexposure to this gas.

See toxicological information (Section 11)

Section 3. Composition, Information on Ingredients

Name	CAS number	% Volume	Exposure limits
Methane	74-82-8	100	**ACGIH TLV (United States, 1/2009).** TWA: 1000 ppm 8 hour(s).

Section 4. First aid measures

No action shall be taken involving any personal risk or without suitable training.If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus.It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

Eye contact : Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact : In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

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

Inhalation : Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

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

Section 5. Fire-fighting measures

Flammability of the product : Flammable.

Auto-ignition temperature : 539.85°C (1003.7°F)

Flash point : Closed cup: -188.15°C (-306.7°F).

Flammable limits : Lower: 5% Upper: 15%

Products of combustion : Decomposition products may include the following materials:
carbon dioxide
carbon monoxide

Fire hazards in the presence of various substances : Extremely flammable in the presence of the following materials or conditions: open flames, sparks and static discharge and oxidizing materials.

Fire-fighting media and instructions : In case of fire, use water spray (fog), foam or dry chemical.

In case of fire, allow gas to burn if flow cannot be shut off immediately. Apply water from a safe distance to cool container and protect surrounding area. If involved in fire, shut off flow immediately if it can be done without risk.

Contains gas under pressure. 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.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions : Immediately contact emergency personnel. Keep unnecessary personnel away. Use suitable protective equipment (section 8). Shut off gas supply if this can be done safely. Isolate area until gas has dispersed.

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Methods for cleaning up : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see section 1 for emergency contact information and section 13 for waste disposal.

Section 7. Handling and storage

Handling : Use only with adequate ventilation. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. High pressure gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Keep container closed. Keep away from heat, sparks and flame. To avoid fire, eliminate ignition sources. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.

Never allow any unprotected part of the body to touch uninsulated pipes or vessels that contain cryogenic liquids. Prevent entrapment of liquid in closed systems or piping without pressure relief devices. Some materials may become brittle at low temperatures and will easily fracture.

Storage : Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame). Segregate from oxidizing materials. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).

For additional information concerning storage and handling refer to Compressed Gas Association pamphlets P-1 Safe Handling of Compressed Gases in Containers and P-12 Safe Handling of Cryogenic Liquids available from the Compressed Gas Association, Inc.

Section 8. Exposure controls/personal protection

Engineering controls : Use only with adequate ventilation. Use process enclosures, 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.

Personal protection

Eyes : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

When working with cryogenic liquids, wear a full face shield.

Skin : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

The applicable standards are (US) 29 CFR 1910.134 and (Canada) Z94.4-93

Hands : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.

Insulated gloves suitable for low temperatures

Personal protection in case of a large spill : Self-contained breathing apparatus (SCBA) should be used to avoid inhalation of the product.

Product name	
methane	**ACGIH TLV (United States, 1/2009).** TWA: 1000 ppm 8 hour(s).

Consult local authorities for acceptable exposure limits.

Section 9. Physical and chemical properties

Molecular weight	: 16.05 g/mole
Molecular formula	: C-H4
Boiling/condensation point	: -161.6°C (-258.9°F)
Melting/freezing point	: -182.6°C (-296.7°F)
Critical temperature	: -82.4°C (-116.3°F)
Vapor density	: 0.55 (Air = 1) Liquid Density@BP: 26.5 lb/ft3 (424.5 kg/m3)
Specific Volume (ft^3/lb)	: 23.6128
Gas Density (lb/ft^3)	: 0.04235

Section 10. Stability and reactivity

Stability and reactivity	: The product is stable.
Incompatibility with various substances	: Extremely reactive or incompatible with the following materials: oxidizing materials.
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Toxicity data

Other toxic effects on humans : No specific information is available in our database regarding the other toxic effects of this material to humans.

Specific effects

Carcinogenic effects	: No known significant effects or critical hazards.
Mutagenic effects	: No known significant effects or critical hazards.
Reproduction toxicity	: No known significant effects or critical hazards.

Section 12. Ecological information

Aquatic ecotoxicity

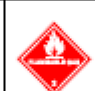
Not available.

Products of degradation	: Products of degradation: carbon oxides (CO, CO_2) and water.
Environmental fate	: Not available.
Environmental hazards	: No known significant effects or critical hazards.
Toxicity to the environment	: Not available.

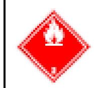
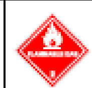
Section 13. Disposal considerations

Product removed from the cylinder must be disposed of in accordance with appropriate Federal, State, local regulation.Return cylinders with residual product to Airgas, Inc.Do not dispose of locally.

Section 14. Transport information

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information
DOT Classification	UN1971	Methane, compressed or Methane or Natural gas, compressed (with high methane content)(Methane)	2.1	Not applicable (gas).		-
	UN1972	Methane, refrigerated liquid				

Methane

TDG Classification	UN1971 UN1972	(Methane)Methane, compressed or Methane or Natural gas, compressed (with high methane content) Methane, refrigerated liquid	2.1	Not applicable (gas).		**Explosive Limit and Limited Quantity Index** 0.125 **ERAP Index** 3000 **Passenger Carrying Ship Index** Forbidden **Passenger Carrying Road or Rail Index** Forbidden
Mexico Classification	UN1971 UN1972	(Methane)Methane, compressed or Methane or Natural gas, compressed (with high methane content) Methane, refrigerated liquid	2.1	Not applicable (gas).		-

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Section 15. Regulatory information

United States

U.S. Federal regulations : **United States inventory (TSCA 8b):** This material is listed or exempted.
SARA 302/304/311/312 extremely hazardous substances: No products were found.
SARA 302/304 emergency planning and notification: No products were found.
SARA 302/304/311/312 hazardous chemicals: methane
SARA 311/312 MSDS distribution - chemical inventory - hazard identification: methane: Fire hazard, Sudden release of pressure

Clean Water Act (CWA) 307: No products were found.

Clean Water Act (CWA) 311: No products were found.

Clean Air Act (CAA) 112 regulated flammable substances: methane

Clean Air Act (CAA) 112 regulated toxic substances: No products were found.

State regulations : **Connecticut Carcinogen Reporting:** This material is not listed.
Connecticut Hazardous Material Survey: This material is not listed.
Florida substances: This material is not listed.
Illinois Chemical Safety Act: This material is not listed.
Illinois Toxic Substances Disclosure to Employee Act: This material is not listed.
Louisiana Reporting: This material is not listed.
Louisiana Spill: This material is not listed.
Massachusetts Spill: This material is not listed.
Massachusetts Substances: This material is listed.
Michigan Critical Material: This material is not listed.
Minnesota Hazardous Substances: This material is not listed.
New Jersey Hazardous Substances: This material is listed.

New Jersey Spill: This material is not listed.
New Jersey Toxic Catastrophe Prevention Act: This material is not listed.
New York Acutely Hazardous Substances: This material is not listed.
New York Toxic Chemical Release Reporting: This material is not listed.
Pennsylvania RTK Hazardous Substances: This material is listed.
Rhode Island Hazardous Substances: This material is not listed.

Canada

WHMIS (Canada) : Class A: Compressed gas.
Class B-1: Flammable gas.

CEPA Toxic substances: This material is listed.
Canadian ARET: This material is not listed.
Canadian NPRI: 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.

Section 16. Other information

United States

Label requirements : GAS:
CONTENTS UNDER PRESURE.
Extremely flammable.
May cause flash fire.
Do not puncture or incinerate container.
Can cause rapid suffocation.
May cause severe frostbite.
LIQUID:
Extremely flammable.
Extremely cold liquid and gas under pressure.
Can cause rapid suffocation.
May cause severe frostbite.

Canada

Label requirements : Class A: Compressed gas.
Class B-1: Flammable gas.

Hazardous Material Information System (U.S.A.) :

Health	1
Flammability	4
Physical hazards	0

liquid:

Health	3
Fire hazard	4
Reactivity	1
Personal protection	

National Fire Protection Association (U.S.A.) :

Methane

liquid:

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.

Material Safety Data Sheet

Ethane

Section 1. Chemical product and company identification

Product name : Ethane

Supplier : AIRGAS INC., on behalf of its subsidiaries
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

Product use : Synthetic/Analytical chemistry.

Synonym : Bimethyl; Dimethyl; Ethyl hydride; Methylmethane; C2H6; UN 1035; UN 1961, R170

MSDS # : 001024

Date of Preparation/Revision : **10/23/2012.**

In case of emergency : 1-866-734-3438

Section 2. Hazards identification

Physical state : Gas. [Compressed gas.]

Emergency overview : WARNING!

GAS:
CONTENTS UNDER PRESURE.
Extremely flammable.
May cause flash fire.
Do not puncture or incinerate container.
Can cause rapid suffocation.
May cause severe frostbite.
LIQUID:
Extremely flammable.
Extremely cold liquid and gas under pressure.
Can cause rapid suffocation.
May cause severe frostbite.

Keep away from heat, sparks and flame. Do not puncture or incinerate container. May cause target organ damage, based on animal data. Use only with adequate ventilation. Keep container closed.

Contact with rapidly expanding gases or liquids can cause frostbite.

Target organs : May cause damage to the following organs: heart, central nervous system (CNS).

Routes of entry : Inhalation

Potential acute health effects

Eyes : Contact with rapidly expanding gas may cause burns or frostbite. Contact with cryogenic liquid can cause frostbite and cryogenic burns.

Skin : Contact with rapidly expanding gas may cause burns or frostbite. Contact with cryogenic liquid can cause frostbite and cryogenic burns.

Inhalation : Acts as a simple asphyxiant.

Ingestion : Ingestion is not a normal route of exposure for gases. Contact with cryogenic liquid can cause frostbite and cryogenic burns.

Potential chronic health effects

Chronic effects : May cause target organ damage, based on animal data.

Target organs : May cause damage to the following organs: heart, central nervous system (CNS).

Medical conditions aggravated by over-exposure : Pre-existing disorders involving any target organs mentioned in this MSDS as being at risk may be aggravated by over-exposure to this product.

See toxicological information (Section 11)

Section 3. Composition, Information on Ingredients

Name	CAS number	% Volume	Exposure limits
Ethane	74-84-0	100	**ACGIH TLV (United States, 2/2010).** TWA: 1000 ppm 8 hour(s).

Section 4. First aid measures

No action shall be taken involving any personal risk or without suitable training.If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus.It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

Eye contact : Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact : In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

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

Inhalation : Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

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

Section 5. Fire-fighting measures

Flammability of the product : Flammable.

Auto-ignition temperature : 472°C (881.6°F)

Flash point : Closed cup: -135.15°C (-211.3°F).

Flammable limits : Lower: 3% Upper: 12.5%

Products of combustion : Decomposition products may include the following materials:
carbon dioxide
carbon monoxide

Fire hazards in the presence of various substances : Extremely flammable in the presence of the following materials or conditions: oxidizing materials.

Fire-fighting media and instructions : In case of fire, use water spray (fog), foam or dry chemical.

In case of fire, allow gas to burn if flow cannot be shut off immediately. Apply water from a safe distance to cool container and protect surrounding area. If involved in fire, shut off flow immediately if it can be done without risk.

Contains gas under pressure. 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.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions : Immediately contact emergency personnel. Keep unnecessary personnel away. Use suitable protective equipment (section 8). Shut off gas supply if this can be done safely. Isolate area until gas has dispersed.

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Methods for cleaning up : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see section 1 for emergency contact information and section 13 for waste disposal.

Section 7. Handling and storage

Handling : Use only with adequate ventilation. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. High pressure gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Keep container closed. Keep away from heat, sparks and flame. To avoid fire, eliminate ignition sources. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Never allow any unprotected part of the body to touch uninsulated pipes or vessels that contain cryogenic liquids. Prevent entrapment of liquid in closed systems or piping without pressure relief devices. Some materials may become brittle at low temperatures and will easily fracture.

Storage : Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame). Segregate from oxidizing materials. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).
For additional information concerning storage and handling refer to Compressed Gas Association pamphlets P-1 Safe Handling of Compressed Gases in Containers and P-12 Safe Handling of Cryogenic Liquids available from the Compressed Gas Association, Inc.

Section 8. Exposure controls/personal protection

Engineering controls : Use only with adequate ventilation. Use process enclosures, 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.

Personal protection

Eyes : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

When working with cryogenic liquids, wear a full face shield.

Skin : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

The applicable standards are (US) 29 CFR 1910.134 and (Canada) Z94.4-93

Hands : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.

Insulated gloves suitable for low temperatures

Personal protection in case of a large spill : Self-contained breathing apparatus (SCBA) should be used to avoid inhalation of the product.

Product name

ethane	**ACGIH TLV (United States, 2/2010).** TWA: 1000 ppm 8 hour(s).

Consult local authorities for acceptable exposure limits.

Section 9. Physical and chemical properties

Molecular weight	: 30.08 g/mole
Molecular formula	: C2-H6
Boiling/condensation point	: -89°C (-128.2°F)
Melting/freezing point	: -183°C (-297.4°F)
Critical temperature	: 32.4°C (90.3°F)
Vapor pressure	: 543 (psig)
Vapor density	: 1.1 (Air = 1) Liquid Density: BP@34.1 lb/ft3 (546 kg/m3)
Specific Volume (ft^3/lb)	: 12.6582
Gas Density (lb/ft^3)	: 0.079

Section 10. Stability and reactivity

Stability and reactivity	: The product is stable.
Incompatibility with various substances	: Extremely reactive or incompatible with the following materials: oxidizing materials.
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Toxicity data

Chronic effects on humans	: May cause damage to the following organs: heart, central nervous system (CNS).
Other toxic effects on humans	: No specific information is available in our database regarding the other toxic effects of this material to humans.

Specific effects

Carcinogenic effects	: No known significant effects or critical hazards.
Mutagenic effects	: No known significant effects or critical hazards.
Reproduction toxicity	: No known significant effects or critical hazards.

Section 12. Ecological information

Aquatic ecotoxicity

Not available.

Products of degradation	: Products of degradation: carbon oxides (CO, CO_2) and water.
Environmental fate	: Not available.
Environmental hazards	: This product shows a low bioaccumulation potential.
Toxicity to the environment	: Not available.

Section 13. Disposal considerations

Product removed from the cylinder must be disposed of in accordance with appropriate Federal, State, local regulation.Return cylinders with residual product to Airgas, Inc.Do not dispose of locally.

Section 14. Transport information

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information

Ethane

DOT Classification	UN1035 UN1961	ETHANE Ethane, refrigerated liquid	2.1	Not applicable (gas).		**Limited quantity** Yes. **Packaging instruction** **Passenger aircraft** Quantity limitation: Forbidden. **Cargo aircraft** Quantity limitation: 150 kg
TDG Classification	UN1035 UN1961	ETHANE Ethane, refrigerated liquid	2.1	Not applicable (gas).		**Explosive Limit and Limited Quantity Index** 0.125 **ERAP Index** 3000 **Passenger Carrying Ship Index** Forbidden **Passenger Carrying Road or Rail Index** Forbidden
Mexico Classification	UN1035 UN1961	ETHANE Ethane, refrigerated liquid	2.1	Not applicable (gas).		-

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Section 15. Regulatory information

United States

U.S. Federal regulations : **TSCA 8(a) IUR**: Not determined
United States inventory (TSCA 8b): This material is listed or exempted.

SARA 302/304/311/312 extremely hazardous substances: No products were found.
SARA 302/304 emergency planning and notification: No products were found.
SARA 302/304/311/312 hazardous chemicals: ethane
SARA 311/312 MSDS distribution - chemical inventory - hazard identification: ethane: Fire hazard, Sudden release of pressure, Immediate (acute) health hazard

Clean Air Act (CAA) 112 accidental release prevention - Flammable Substances: Ethane

Clean Air Act (CAA) 112 regulated flammable substances: ethane

State regulations : **Connecticut Carcinogen Reporting**: This material is not listed.
Connecticut Hazardous Material Survey: This material is not listed.
Florida substances: This material is not listed.
Illinois Chemical Safety Act: This material is not listed.
Illinois Toxic Substances Disclosure to Employee Act: This material is not listed.
Louisiana Reporting: This material is not listed.
Louisiana Spill: This material is not listed.
Massachusetts Spill: This material is not listed.
Massachusetts Substances: This material is listed.
Michigan Critical Material: This material is not listed.
Minnesota Hazardous Substances: This material is not listed.
New Jersey Hazardous Substances: This material is listed.
New Jersey Spill: This material is not listed.
New Jersey Toxic Catastrophe Prevention Act: This material is not listed.
New York Acutely Hazardous Substances: This material is not listed.
New York Toxic Chemical Release Reporting: This material is not listed.
Pennsylvania RTK Hazardous Substances: This material is listed.
Rhode Island Hazardous Substances: This material is not listed.

Canada

WHMIS (Canada) : Class A: Compressed gas.
Class B-1: Flammable gas.

CEPA Toxic substances: This material is listed.
Canadian ARET: This material is not listed.
Canadian NPRI: 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.

Section 16. Other information

United States

Label requirements : GAS:
CONTENTS UNDER PRESURE.
Extremely flammable.
May cause flash fire.
Do not puncture or incinerate container.
Can cause rapid suffocation.
May cause severe frostbite.
LIQUID:
Extremely flammable.
Extremely cold liquid and gas under pressure.
Can cause rapid suffocation.
May cause severe frostbite.

Canada

Label requirements : Class A: Compressed gas.
Class B-1: Flammable gas.

Hazardous Material Information System (U.S.A.) :

Health	1
Flammability	4
Physical hazards	0

liquid:

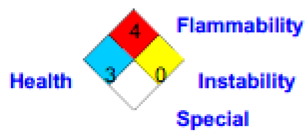
Health	3

Ethane

Fire hazard	4
Reactivity	0
Personal protection	

National Fire Protection Association (U.S.A.) :

liquid:



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.

Material Safety Data Sheet

Propane

Section 1. Chemical product and company identification

Product name	:	Propane
Supplier	:	AIRGAS INC., on behalf of its subsidiaries 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
Product use	:	Synthetic/Analytical chemistry.
Synonym	:	n-Propane; Dimethylmethane; Freon 290; Liquefied petroleum gas; Lpg; Propyl hydride; R 290; C3H8; UN 1075; UN 1978; A-108; Hydrocarbon propellant.
MSDS #	:	001045
Date of Preparation/Revision	:	**8/19/2013.**
In case of emergency	:	1-866-734-3438

Section 2. Hazards identification

Physical state	:	Gas. [COLORLESS LIQUEFIED COMPRESSED GAS; ODORLESS BUT MAY HAVE SKUNK ODOR ADDED.]
Emergency overview	:	WARNING! FLAMMABLE GAS. MAY CAUSE FLASH FIRE. MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA. CONTENTS UNDER PRESSURE. Keep away from heat, sparks and flame. Do not puncture or incinerate container. May cause target organ damage, based on animal data. Use only with adequate ventilation. Keep container closed. Contact with rapidly expanding gases can cause frostbite.
Target organs	:	May cause damage to the following organs: the nervous system, heart, central nervous system (CNS).
Routes of entry	:	Inhalation
Potential acute health effects		
Eyes	:	Contact with rapidly expanding gas may cause burns or frostbite.
Skin	:	Contact with rapidly expanding gas may cause burns or frostbite.
Inhalation	:	Acts as a simple asphyxiant.
Ingestion	:	Ingestion is not a normal route of exposure for gases
Potential chronic health effects		
Chronic effects	:	May cause target organ damage, based on animal data.
Target organs	:	May cause damage to the following organs: the nervous system, heart, central nervous system (CNS).
Medical conditions aggravated by over-exposure	:	Pre-existing disorders involving any target organs mentioned in this MSDS as being at risk may be aggravated by over-exposure to this product.

See toxicological information (Section 11)

Section 3. Composition, Information on Ingredients

Name	CAS number	% Volume	Exposure limits
Propane	74-98-6	100	**ACGIH TLV (United States, 3/2012).** TWA: 1000 ppm 8 hour(s). **NIOSH REL (United States, 1/2013).** TWA: 1800 mg/m³ 10 hour(s). TWA: 1000 ppm 10 hour(s). **OSHA PEL (United States, 6/2010).** TWA: 1800 mg/m³ 8 hour(s). TWA: 1000 ppm 8 hour(s). **OSHA PEL 1989 (United States, 3/1989).** TWA: 1800 mg/m³ 8 hour(s). TWA: 1000 ppm 8 hour(s).

Section 4. First aid measures

No action shall be taken involving any personal risk or without suitable training.If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus.It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

Eye contact : Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact : In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

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

Inhalation : Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

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

Section 5. Fire-fighting measures

Flammability of the product : Flammable.

Auto-ignition temperature : 450°C (842°F)

Flash point : Closed cup: -104°C (-155.2°F). Open cup: -104°C (-155.2°F).

Flammable limits : Lower: 2.1% Upper: 9.5%

Products of combustion : Decomposition products may include the following materials:
carbon dioxide
carbon monoxide

Fire hazards in the presence of various substances : Extremely flammable in the presence of the following materials or conditions: open flames, sparks and static discharge and oxidizing materials.

Fire-fighting media and instructions : In case of fire, use water spray (fog), foam or dry chemical.

In case of fire, allow gas to burn if flow cannot be shut off immediately. Apply water from a safe distance to cool container and protect surrounding area. If involved in fire, shut off flow immediately if it can be done without risk.

Contains gas under pressure. 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.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions : Immediately contact emergency personnel. Keep unnecessary personnel away. Use suitable protective equipment (section 8). Shut off gas supply if this can be done safely. Isolate area until gas has dispersed.

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Methods for cleaning up : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see section 1 for emergency contact information and section 13 for waste disposal.

Section 7. Handling and storage

Handling : Use only with adequate ventilation. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. High pressure gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Keep container closed. Keep away from heat, sparks and flame. To avoid fire, eliminate ignition sources. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.

Storage : Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame). Segregate from oxidizing materials. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).

Section 8. Exposure controls/personal protection

Engineering controls : Use only with adequate ventilation. Use process enclosures, 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.

Personal protection

Eyes : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

Skin : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

The applicable standards are (US) 29 CFR 1910.134 and (Canada) Z94.4-93

Hands : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.

Personal protection in case of a large spill : Self-contained breathing apparatus (SCBA) should be used to avoid inhalation of the product.

Product name

propane	**ACGIH TLV (United States, 3/2012).** TWA: 1000 ppm 8 hour(s). **NIOSH REL (United States, 1/2013).** TWA: 1800 mg/m³ 10 hour(s). TWA: 1000 ppm 10 hour(s). **OSHA PEL (United States, 6/2010).** TWA: 1800 mg/m³ 8 hour(s). TWA: 1000 ppm 8 hour(s). **OSHA PEL 1989 (United States, 3/1989).** TWA: 1800 mg/m³ 8 hour(s).

TWA: 1000 ppm 8 hour(s).

Consult local authorities for acceptable exposure limits.

Section 9. Physical and chemical properties

Molecular weight	:	44.11 g/mole
Molecular formula	:	C3-H8
Boiling/condensation point	:	-42°C (-43.6°F)
Melting/freezing point	:	-189.7°C (-309.5°F)
Critical temperature	:	96.6°C (205.9°F)
Vapor pressure	:	109 (psig)
Vapor density	:	1.6 (Air = 1)
Specific Volume (ft^3/lb)	:	8.6206
Gas Density (lb/ft^3)	:	0.116

Section 10. Stability and reactivity

Stability and reactivity	:	The product is stable.
Incompatibility with various substances	:	Extremely reactive or incompatible with the following materials: oxidizing materials.
Hazardous decomposition products	:	Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Hazardous polymerization	:	Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Toxicity data

Product/ingredient name	Result	Species	Dose	Exposure
propane	LC50 Inhalation Gas.	Rat	>800000 ppm	15 minutes

IDLH	:	2100 ppm
Chronic effects on humans	:	May cause damage to the following organs: the nervous system, heart, central nervous system (CNS).
Other toxic effects on humans	:	No specific information is available in our database regarding the other toxic effects of this material to humans.

Specific effects

Carcinogenic effects	:	No known significant effects or critical hazards.
Mutagenic effects	:	No known significant effects or critical hazards.
Reproduction toxicity	:	No known significant effects or critical hazards.

Section 12. Ecological information

Aquatic ecotoxicity

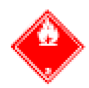
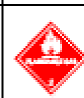
Not available.

Products of degradation	:	Products of degradation: carbon oxides (CO, CO_2) and water.
Environmental fate	:	Not available.
Environmental hazards	:	This product shows a low bioaccumulation potential.
Toxicity to the environment	:	Not available.

Section 13. Disposal considerations

Product removed from the cylinder must be disposed of in accordance with appropriate Federal, State, local regulation.Return cylinders with residual product to Airgas, Inc.Do not dispose of locally.

Section 14. Transport information

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information
DOT Classification	UN1978	PROPANE	2.1	Not applicable (gas).		**Limited quantity** Yes. **Packaging instruction** **Passenger aircraft** Quantity limitation: Forbidden. **Cargo aircraft** Quantity limitation: 150 kg **Special provisions** 19, T50
TDG Classification	UN1978	PROPANE	2.1	Not applicable (gas).		**Explosive Limit and Limited Quantity Index** 0.125 **ERAP Index** 3000 **Passenger Carrying Ship Index** 65 **Passenger Carrying Road or Rail Index** Forbidden **Special provisions** 29, 42
Mexico Classification	UN1978	PROPANE	2.1	Not applicable (gas).		-

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Section 15. Regulatory information

United States

U.S. Federal regulations : **TSCA 8(a) IUR**: Not determined
United States inventory (TSCA 8b): This material is listed or exempted.
SARA 302/304/311/312 extremely hazardous substances: No products were found.
SARA 302/304 emergency planning and notification: No products were found.
SARA 302/304/311/312 hazardous chemicals: propane
SARA 311/312 MSDS distribution - chemical inventory - hazard identification:
propane: Fire hazard, Sudden release of pressure
Clean Air Act (CAA) 112 accidental release prevention - Flammable Substances:
Propane

Clean Air Act (CAA) 112 regulated flammable substances: propane

State regulations : **Connecticut Carcinogen Reporting**: This material is not listed.
Connecticut Hazardous Material Survey: This material is not listed.
Florida substances: This material is not listed.
Illinois Chemical Safety Act: This material is not listed.
Illinois Toxic Substances Disclosure to Employee Act: This material is not listed.
Louisiana Reporting: This material is not listed.
Louisiana Spill: This material is not listed.
Massachusetts Spill: This material is not listed.
Massachusetts Substances: This material is listed.
Michigan Critical Material: This material is not listed.
Minnesota Hazardous Substances: This material is not listed.
New Jersey Hazardous Substances: This material is listed.
New Jersey Spill: This material is not listed.
New Jersey Toxic Catastrophe Prevention Act: This material is not listed.
New York Acutely Hazardous Substances: This material is not listed.
New York Toxic Chemical Release Reporting: This material is not listed.
Pennsylvania RTK Hazardous Substances: This material is listed.
Rhode Island Hazardous Substances: This material is not listed.

Canada

WHMIS (Canada) : Class A: Compressed gas.
Class B-1: Flammable gas.
CEPA Toxic substances: This material is not listed.
Canadian ARET: This material is not listed.
Canadian NPRI: 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.

Section 16. Other information

United States

Label requirements : FLAMMABLE GAS.
MAY CAUSE FLASH FIRE.
MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA.
CONTENTS UNDER PRESSURE.

Canada

Label requirements : Class A: Compressed gas.
Class B-1: Flammable gas.

Propane

Hazardous Material Information System (U.S.A.) :

Health	*	1
Flammability		4
Physical hazards		2

National Fire Protection Association (U.S.A.) :

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.

Material Safety Data Sheet

N-Butane

Section 1. Chemical product and company identification

Product name : N-Butane

Supplier : AIRGAS INC., on behalf of its subsidiaries
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

Product use : Synthetic/Analytical chemistry.

Synonym : n-Butane; Diethyl; Freon 600; Liquefied petroleum gas; LPG; n-C4H10; Butanen; Butani; Methylethylmethane; UN 1011; UN 1075; A-17; Bu-Gas.

MSDS # : 001007

Date of Preparation/Revision : **7/10/2013.**

In case of emergency : 1-866-734-3438

Section 2. Hazards identification

Physical state : Gas. [COLORLESS LIQUEFIED COMPRESS GAS WITH GASOLINE-LIKE ODOR.]

Emergency overview : WARNING!

FLAMMABLE GAS.
MAY CAUSE FLASH FIRE.
MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA.
CONTENTS UNDER PRESSURE.

Keep away from heat, sparks and flame. Do not puncture or incinerate container. May cause target organ damage, based on animal data. Use only with adequate ventilation. Keep container closed.

Contact with rapidly expanding gases can cause frostbite.

Target organs : May cause damage to the following organs: central nervous system (CNS).

Routes of entry : Inhalation

Potential acute health effects

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

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

Inhalation : Acts as a simple asphyxiant.

Ingestion : Ingestion is not a normal route of exposure for gases

Potential chronic health effects

Target organs : May cause damage to the following organs: central nervous system (CNS).

Medical conditions aggravated by over-exposure : Pre-existing disorders involving any target organs mentioned in this MSDS as being at risk may be aggravated by over-exposure to this product.

See toxicological information (Section 11)

Section 3. Composition, Information on Ingredients

Name	CAS number	% Volume	Exposure limits
N-Butane	106-97-8	100	**ACGIH TLV (United States, 3/2012).** TWA: 1000 ppm 8 hour(s). **NIOSH REL (United States, 1/2013).** TWA: 1900 mg/m³ 10 hour(s). TWA: 800 ppm 10 hour(s). **OSHA PEL 1989 (United States, 3/1989).** TWA: 1900 mg/m³ 8 hour(s). TWA: 800 ppm 8 hour(s).

Section 4. First aid measures

No action shall be taken involving any personal risk or without suitable training.If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus.It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

Eye contact : Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact : In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.

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

Inhalation : Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

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

Section 5. Fire-fighting measures

Flammability of the product : Flammable.

Auto-ignition temperature : 286.85°C (548.3°F)

Flash point : Closed cup: -60.15°C (-76.3°F).

Flammable limits : Lower: 1.6% Upper: 8.5%

Products of combustion : Decomposition products may include the following materials:
carbon dioxide
carbon monoxide

Fire hazards in the presence of various substances : Extremely flammable in the presence of the following materials or conditions: open flames, sparks and static discharge and oxidizing materials.

Fire-fighting media and instructions : In case of fire, use water spray (fog), foam or dry chemical.

In case of fire, allow gas to burn if flow cannot be shut off immediately. Apply water from a safe distance to cool container and protect surrounding area. If involved in fire, shut off flow immediately if it can be done without risk.

Contains gas under pressure. 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.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions : Immediately contact emergency personnel. Keep unnecessary personnel away. Use suitable protective equipment (section 8). Shut off gas supply if this can be done safely. Isolate area until gas has dispersed.

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Methods for cleaning up : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see section 1 for emergency contact information and section 13 for waste disposal.

Section 7. Handling and storage

Handling : Use only with adequate ventilation. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. High pressure gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Keep container closed. Keep away from heat, sparks and flame. To avoid fire, eliminate ignition sources. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.

Storage : Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame). Segregate from oxidizing materials. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).

Section 8. Exposure controls/personal protection

Engineering controls : Use only with adequate ventilation. Use process enclosures, 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.

Personal protection

Eyes : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

Skin : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

The applicable standards are (US) 29 CFR 1910.134 and (Canada) Z94.4-93

Hands : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.

Personal protection in case of a large spill : Self-contained breathing apparatus (SCBA) should be used to avoid inhalation of the product.

Product name

Butane	**ACGIH TLV (United States, 3/2012).** TWA: 1000 ppm 8 hour(s). **NIOSH REL (United States, 1/2013).** TWA: 1900 mg/m³ 10 hour(s). TWA: 800 ppm 10 hour(s). **OSHA PEL 1989 (United States, 3/1989).** TWA: 1900 mg/m³ 8 hour(s). TWA: 800 ppm 8 hour(s).

Consult local authorities for acceptable exposure limits.

Section 9. Physical and chemical properties

Molecular weight : 58.14 g/mole

Molecular formula : C4-H10

Boiling/condensation point : -0.6°C (30.9°F)

Melting/freezing point : -135.4°C (-211.7°F)

Critical temperature : 151.9°C (305.4°F)

Vapor pressure : 16.3 (psig)

Vapor density : 2 (Air = 1)

N-Butane	
Specific Volume (ft^3/lb)	: 6.435
Gas Density (lb/ft^3)	: 0.1554

Section 10. Stability and reactivity

Stability and reactivity	: The product is stable.
Incompatibility with various substances	: Extremely reactive or incompatible with the following materials: oxidizing materials.
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Toxicity data

Product/ingredient name	Result	Species	Dose	Exposure
Butane	LC50 Inhalation Vapor	Rat	658000 mg/m3	4 hours

Chronic effects on humans	: May cause damage to the following organs: central nervous system (CNS).
Other toxic effects on humans	: No specific information is available in our database regarding the other toxic effects of this material to humans.

Specific effects

Carcinogenic effects	: No known significant effects or critical hazards.
Mutagenic effects	: No known significant effects or critical hazards.
Reproduction toxicity	: No known significant effects or critical hazards.

Section 12. Ecological information

Aquatic ecotoxicity

Not available.

Products of degradation	: Products of degradation: carbon oxides (CO, CO_2) and water.
Environmental fate	: Not available.
Environmental hazards	: No known significant effects or critical hazards.
Toxicity to the environment	: Not available.

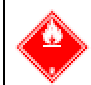
Section 13. Disposal considerations

Product removed from the cylinder must be disposed of in accordance with appropriate Federal, State, local regulation.Return cylinders with residual product to Airgas, Inc.Do not dispose of locally.

Section 14. Transport information

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information
DOT Classification	UN1011	BUTANE	2.1	Not applicable (gas).		**Limited quantity** Yes. **Packaging instruction** **Passenger aircraft** Quantity limitation: Forbidden. **Cargo aircraft** Quantity limitation:

N-Butane

						150 kg **Special provisions** 19, T50
TDG Classification	UN1011	BUTANE	2.1	Not applicable (gas).		**Explosive Limit and Limited Quantity Index** 0.125 **ERAP Index** 3000 **Passenger Carrying Ship Index** Forbidden **Passenger Carrying Road or Rail Index** Forbidden **Special provisions** 29
Mexico Classification	UN1011	BUTANE	2.1	Not applicable (gas).		-

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Section 15. Regulatory information

United States

U.S. Federal regulations : **TSCA 8(a) IUR**: Not determined
United States inventory (TSCA 8b): This material is listed or exempted.

SARA 302/304/311/312 extremely hazardous substances: No products were found.
SARA 302/304 emergency planning and notification: No products were found.
SARA 302/304/311/312 hazardous chemicals: Butane
SARA 311/312 MSDS distribution - chemical inventory - hazard identification: Butane: Fire hazard, Sudden release of pressure

Clean Water Act (CWA) 311: No products were found.

Clean Air Act (CAA) 112 regulated flammable substances: Butane

State regulations : **Connecticut Carcinogen Reporting**: This material is not listed.
Connecticut Hazardous Material Survey: This material is not listed.
Florida substances: This material is not listed.
Illinois Chemical Safety Act: This material is not listed.
Illinois Toxic Substances Disclosure to Employee Act: This material is not listed.
Louisiana Reporting: This material is not listed.
Louisiana Spill: This material is not listed.
Massachusetts Spill: This material is not listed.
Massachusetts Substances: This material is listed.

Michigan Critical Material: This material is not listed.
Minnesota Hazardous Substances: This material is not listed.
New Jersey Hazardous Substances: This material is listed.
New Jersey Spill: This material is not listed.
New Jersey Toxic Catastrophe Prevention Act: This material is not listed.
New York Acutely Hazardous Substances: This material is not listed.
New York Toxic Chemical Release Reporting: This material is not listed.
Pennsylvania RTK Hazardous Substances: This material is listed.
Rhode Island Hazardous Substances: This material is not listed.

Canada

WHMIS (Canada) : Class A: Compressed gas.
Class B-1: Flammable gas.

CEPA Toxic substances: This material is not listed.
Canadian ARET: This material is not listed.
Canadian NPRI: 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.

Section 16. Other information

United States

Label requirements : FLAMMABLE GAS.
MAY CAUSE FLASH FIRE.
MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA.
CONTENTS UNDER PRESSURE.

Canada

Label requirements : Class A: Compressed gas.
Class B-1: Flammable gas.

Hazardous Material Information System (U.S.A.) :

Health	*	1
Flammability		4
Physical hazards		0

National Fire Protection Association (U.S.A.) :

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.

Material Safety Data Sheet

Nitrogen

Section 1. Chemical product and company identification

Product name	:	Nitrogen
Supplier	:	AIRGAS INC., on behalf of its subsidiaries 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
Product use	:	Synthetic/Analytical chemistry. Liquid – cryogenic coolant.
Synonym	:	nitrogen (dot); nitrogen gas; Nitrogen NF, LIN, Cryogenic Liquid Nitrogen, Liquid Nitrogen
MSDS #	:	001040
Date of Preparation/ Revision	:	**11/22/2013.**
In case of emergency	:	1-866-734-3438

Section 2. Hazards identification

Physical state	:	Gas. [NORMALLY A COLORLESS GAS: MAY BE A CLEAR COLORLESS LIQUID AT LOW TEMPERATURES. SOLD AS A COMPRESSED GAS OR LIQUID IN STEEL CYLINDERS.]
Emergency overview	:	WARNING! GAS: CONTENTS UNDER PRESURE. Do not puncture or incinerate container. Can cause rapid suffocation. May cause severe frostbite. LIQUID: Extremely cold liquid and gas under pressure. Can cause rapid suffocation. May cause severe frostbite. Do not puncture or incinerate container. May cause target organ damage, based on animal data. Contact with rapidly expanding gases or liquids can cause frostbite.
Target organs	:	May cause damage to the following organs: lungs.
Routes of entry	:	Inhalation

Potential acute health effects

Eyes	:	Contact with rapidly expanding gas may cause burns or frostbite. Contact with cryogenic liquid can cause frostbite and cryogenic burns.
Skin	:	Contact with rapidly expanding gas may cause burns or frostbite. Contact with cryogenic liquid can cause frostbite and cryogenic burns.
Inhalation	:	Acts as a simple asphyxiant.
Ingestion	:	Ingestion is not a normal route of exposure for gases. Contact with cryogenic liquid can cause frostbite and cryogenic burns.

Potential chronic health effects

Chronic effects	:	May cause target organ damage, based on animal data.
Target organs	:	May cause damage to the following organs: lungs.
Medical conditions aggravated by over-exposure	:	Pre-existing disorders involving any target organs mentioned in this MSDS as being at risk may be aggravated by over-exposure to this product.

See toxicological information (Section 11)

Section 3. Composition, Information on Ingredients

Name	CAS number	% Volume	Exposure limits
Nitrogen	7727-37-9	100	Oxygen Depletion [Asphyxiant]

Section 4. First aid measures

No action shall be taken involving any personal risk or without suitable training.If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus.It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

Eye contact : Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.

Skin contact : None expected.

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

Inhalation : Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.

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

Section 5. Fire-fighting measures

Flammability of the product : Non-flammable.

Products of combustion : Decomposition products may include the following materials: nitrogen oxides

Fire-fighting media and instructions : Use an extinguishing agent suitable for the surrounding fire.

Apply water from a safe distance to cool container and protect surrounding area. If involved in fire, shut off flow immediately if it can be done without risk.

Contains gas under pressure. In a fire or if heated, a pressure increase will occur and the container may burst or explode.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions : Immediately contact emergency personnel. Keep unnecessary personnel away. Use suitable protective equipment (section 8). Shut off gas supply if this can be done safely. Isolate area until gas has dispersed.

Environmental precautions : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Methods for cleaning up : Immediately contact emergency personnel. Stop leak if without risk. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Handling : High pressure gas. 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 drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.

Never allow any unprotected part of the body to touch uninsulated pipes or vessels that contain cryogenic liquids. Prevent entrapment of liquid in closed systems or piping without pressure relief devices. Some materials may become brittle at low temperatures and will easily fracture.

Nitrogen

Storage	: Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). For additional information concerning storage and handling refer to Compressed Gas Association pamphlets P-1 Safe Handling of Compressed Gases in Containers and P-12 Safe Handling of Cryogenic Liquids available from the Compressed Gas Association, Inc.

Section 8. Exposure controls/personal protection

Engineering controls : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits.

Personal protection

Eyes : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

When working with cryogenic liquids, wear a full face shield.

Skin : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

The applicable standards are (US) 29 CFR 1910.134 and (Canada) Z94.4-93

Hands : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.

Insulated gloves suitable for low temperatures

Personal protection in case of a large spill : Self-contained breathing apparatus (SCBA) should be used to avoid inhalation of the product.

Product name

Nitrogen	Oxygen Depletion [Asphyxiant]

Consult local authorities for acceptable exposure limits.

Section 9. Physical and chemical properties

Molecular weight	: 28.02 g/mole
Molecular formula	: N2
Boiling/condensation point	: -195.79°C (-320.4°F)
Melting/freezing point	: -210.01°C (-346°F)
Critical temperature	: -146.9°C (-232.4°F)
Vapor density	: 0.967 (Air = 1) Liquid Density@BP: 50.46 lb/ft3 (808.3 kg/m3)
Specific Volume (ft^3/lb)	: 13.8889
Gas Density (lb/ft^3)	: 0.072

Section 10. Stability and reactivity

Stability and reactivity	: The product is stable.
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

Toxicity data

Chronic effects on humans : May cause damage to the following organs: lungs.

Other toxic effects on humans : No specific information is available in our database regarding the other toxic effects of this material to humans.

Specific effects

Carcinogenic effects : No known significant effects or critical hazards.

Mutagenic effects : No known significant effects or critical hazards.

Reproduction toxicity : No known significant effects or critical hazards.

Section 12. Ecological information

Aquatic ecotoxicity

Not available.

Environmental fate : Not available.

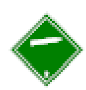
Environmental hazards : No known significant effects or critical hazards.

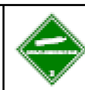
Toxicity to the environment : Not available.

Section 13. Disposal considerations

Product removed from the cylinder must be disposed of in accordance with appropriate Federal, State, local regulation.Return cylinders with residual product to Airgas, Inc.Do not dispose of locally.

Section 14. Transport information

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information
DOT Classification	UN1066 UN1977	NITROGEN, COMPRESSED Nitrogen, refrigerated liquid	2.2	Not applicable (gas).		**Limited quantity** Yes. **Packaging instruction** **Passenger aircraft** Quantity limitation: 75 kg **Cargo aircraft** Quantity limitation: 150 kg
TDG Classification	UN1066 UN1977	NITROGEN, COMPRESSED Nitrogen, refrigerated liquid	2.2	Not applicable (gas).		**Explosive Limit and Limited Quantity Index** 0.125 **Passenger Carrying Road or Rail Index** 75

Nitrogen						
Mexico Classification	UN1066 UN1977	NITROGEN, COMPRESSED Nitrogen, refrigerated liquid	2.2	Not applicable (gas).		-

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Section 15. Regulatory information

United States

U.S. Federal regulations : **TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted.
United States inventory (TSCA 8b): This material is listed or exempted.
SARA 302/304: No products were found.
SARA 311/312 Hazards identification: Sudden release of pressure, Delayed (chronic) health hazard

State regulations : **Connecticut Carcinogen Reporting**: This material is not listed.
Connecticut Hazardous Material Survey: This material is not listed.
Florida substances: This material is not listed.
Illinois Chemical Safety Act: This material is not listed.
Illinois Toxic Substances Disclosure to Employee Act: This material is not listed.
Louisiana Reporting: This material is not listed.
Louisiana Spill: This material is not listed.
Massachusetts Spill: This material is not listed.
Massachusetts Substances: This material is listed.
Michigan Critical Material: This material is not listed.
Minnesota Hazardous Substances: This material is not listed.
New Jersey Hazardous Substances: This material is listed.
New Jersey Spill: This material is not listed.
New Jersey Toxic Catastrophe Prevention Act: This material is not listed.
New York Acutely Hazardous Substances: This material is not listed.
New York Toxic Chemical Release Reporting: This material is not listed.
Pennsylvania RTK Hazardous Substances: This material is listed.
Rhode Island Hazardous Substances: This material is not listed.

Canada

WHMIS (Canada) : Class A: Compressed gas.
CEPA Toxic substances: This material is not listed.
Canadian ARET: This material is not listed.
Canadian NPRI: This material is not listed.
Alberta Designated Substances: This material is not listed.
Ontario Designated Substances: This material is not listed.
Quebec Designated Substances: This material is not listed.

Section 16. Other information

United States

Label requirements : GAS:
CONTENTS UNDER PRESURE.
Do not puncture or incinerate container.
Can cause rapid suffocation.
May cause severe frostbite.
LIQUID:
Extremely cold liquid and gas under pressure.
Can cause rapid suffocation.
May cause severe frostbite.

Canada

Nitrogen

Label requirements : Class A: Compressed gas.

Hazardous Material Information System (U.S.A.) :

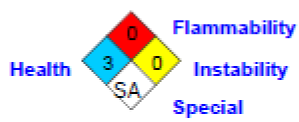
Health	0
Flammability	0
Physical hazards	0

liquid:

Health	3
Fire hazard	0
Reactivity	0
Personal protection	

National Fire Protection Association (U.S.A.) :

liquid:



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