Dr. Bruce Vrana
Dr. Wen K. Shieh
Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Science
University of Pennsylvania
220 S. 33rd Street
Philadelphia, PA 19104
April 17, 2018

Dear Dr. Vrana, Dr. Seider, Dr. Shieh, and Mr. Adam Brostow,

Enclosed is a proposed pilot plant using oxy fuel for clean energy generation, a project proposed by Mr. Adam A. Brostow. Various scenarios of enriched oxygen streams were investigated to determine which enrichment was the most economical and made the most sense.

The process was designed using ASPEN simulations and each scenario was rigorously modeled. Oxygen purities of 36 mol. %, 53 mol. %, and 95 mol. % were modeled and the net power produced was 30 MW. The combustion portion of the process was treated as a black box. The various scenarios were assumed to operate 90% of days at 100% capacity.

Profitability analysis revealed the three scenarios to be unprofitable. Therefore, we do not recommend investing in this technology given our current design. However, the profitability is sensitive to nitrogen price and the monetizing of oxy fuel benefits.

Sincerely,

Patrick Hally	Najíb Muqeem	Colin Richter	Tim Schanstra

Oxy Fuel for Clean Energy Generation

Patrick Hally | Najib Muqeem | Colin Richter | Tim Schanstra

Project submitted to: Dr. Wen K. Shieh

Prof. Bruce M. Vrana

Project proposed by: Mr. Adam A. Brostow

Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Sciences
April 17, 2018

Table of Contents

Abstract **5**
1.1 Abstract 6

Introduction and Objective-time Chart **7**
2.1 Introduction 8
2.2 Objective Time Chart 10

Market and Competitive Analysis **11**
3.1 Market Analysis 12
3.1.1 Energy 12
3.1.2 Nitrogen 15
3.1.3 Carbon Dioxide 17
3.2 Competitive Analysis 18

Preliminary Process Synthesis **19**
4.1 Overall Process 20
4.2 Scenarios 22

Assembly of Database **24**
5.1 Thermophysical Property and Price Data 25
5.2 Toxicity Data 26

Process Flow Diagram and Material Balance **28**

Process Description **35**
7.1 Overall Process 36
7.2 36% Case 37
7.3 53% Case 38
7.4 95% Case 39

Energy Balance and Utility Requirements **41**

Equipment List and Unit Descriptions **45**

Specification Sheets **56**
10.1 36% Case 57
10.2 53% Case 63
10.3 95% Case 69

Equipment Cost Summary **75**

Fixed-Capital Investment Summary **78**

Operating and Variable Costs **83**

Important Considerations **88**

14.1 Plant Location 89

14.2 Environmental Issues 89

14.3 Safety 90

14.4 Plant Startup 91

Profitability Analysis **92**

Conclusion and Recommendations **98**

Acknowledgements **101**

Bibliography **103**

18.1 Citations 104

Appendices **107**

Appendix A: Sample Calculations 108

Appendix B: EPA New Source Requirements 109

Appendix C: ASPEN Block and Stream Reports 110

36% Case 110

Flowsheet 110

Block Report 110

Stream Report 124

53% Case 126

Flowsheet 126

Block Report 126

Stream Report 147

95% Case 151

Flowsheet 151

Block Report 152

Stream Report 195

Section 1
Abstract

1.1 Abstract

This process explores several concentrations of oxygen-enriched air streams (oxy fuel) in combination with natural gas to generate steam for a steam turbine power plant with 30 MW capacity. The proposed location for this plant is the gulf coast of the United States. The oxy fuel concentrations tested were 36 mol. %, 53 mol. %, and 95 mol. %. Nitrogen removed from air would be sold as well as the 30 MW of electricity. The three oxygen purities were not profitable for the most realistic prices of electricity, nitrogen, and natural gas. However, the scenarios were all profitable with prices of nitrogen above $0.015/lb. Additionally, the profitability could be improved with higher electricity prices or better thermal efficiency. A key takeaway is that the level of oxygen purity did not have a major effect on profitability for a given nitrogen price.

Section 2
Introduction and Objective-time Chart

2.1 Introduction

The motivation for this project comes from Linde's Schwarze Pumpe which was a coal fired power plant that used oxy fuel technology. This oxy fuel technology uses Air Separation Units (ASU) to take air and make an oxygen enriched stream and a nitrogen enriched stream. The goal for this project is to create a similar pilot plant, but one that uses natural gas instead of coal and uses the ASU technology from Air Products. The project uses three different oxygen enrichment levels (36%, 53%, and 95%). The oxy fuel energy generation process burns natural gas in an enriched oxygen stream as the primary oxidant. This enriched oxygen stream is an improvement over the amount of oxygen in air (21%) which is typically used in combustion. Higher oxygen concentrations allow for higher flame temperatures for certain processes. However, for this process since a higher flame temp would not be beneficial to the process, the flue gas can be recycled to reduce it to an appropriate level. A higher flame temp would promote more production of NOx, which is a pollutant that this process tries to reduce.

An advantage of the oxy fuel process is that it will produce up to 75% less flue gas by volume. This means less equipment will be needed to manage the flue gas coming out of the system which reduces capital costs. Less flue gas is the result of less nitrogen present in the furnace when combustion takes place. A huge benefit for using an oxygen enriched stream in combustion is that the flue gas is essentially all carbon dioxide and water. NO_x is reduced due to a lower amount of nitrogen in the furnace. Since the flue gas has reduced NO_x, the carbon dioxide becomes easier to separate from the rest of the flue gas making this process extremely attractive for carbon sequestration.

In the future, where there is a price on emitting carbon and/or fossil fuels become more expensive, this technology could become more economical. However, in its current state, this process is more expensive than a traditional power plant that uses air. The amount of power needed to separate the oxygen from the air ranged from 25-37.5% of total production of the pilot plant. This means that in order to produce the 30 MWs of net power that was required, 40-48 MWs of raw power needed to be produced. This is a large quantity of energy that goes into making an enriched oxygen stream.

Another benefit of this process is that you can extract a nearly pure nitrogen stream which can be sold as a valuable product. This helps make the plant more economical, assuming that there is a customer nearby willing to buy nitrogen. Most ASUs see nitrogen as the main product and the enriched oxygen stream as more of a waste stream. This process tries to use the oxygen stream to make something useful in the form of electricity. This plant will be built in the Gulf Region with a customer close by who will buy the nitrogen produced at a purity of greater than 99%. This project will weigh the economic potential of each oxygen enriched stream (36%, 53%, or 95%).

2.2 Objective Time Chart

Project Name Oxy Fuel for Clean Energy Generation

Project Advisors Adam A. Brostow, Wen K. Shieh, Bruce M. Vrana

Project Leaders Patrick Hally, Najíb Muqeem, Colin Richter, Tim Schanstra

Specific Goals Develop a pilot plant that produces 30 net Megawatts of electricity using a conventional steam turbine. The feed to the plant will be an oxygen enriched stream at 36, 53, or 95% oxygen and natural gas. The different costs of using the three streams should be analyzed.

Project Scope

In Scope:

-Produce 30 net MW of electricity
-Produce a Nitrogen rich stream to sell as by-product
-Determine equipment needed and operating conditions
-Size equipment used
-Analyze profitability and economics of the three different oxygen enriched streams
-Develop a model for double column and single column ASUs

Out of Scope:

-Rigorously model the combustion unit
-Test assumptions made based on thermodynamic principles
-Building Pilot Plant to test Aspen results
-Rigorously model the costs and profitability of carbon capture

Deliverables

-Flowsheet outlining double column and single column ASU
-Aspen simulation for three different oxygen concentrations
-Financial analysis of the ASU
-Mass and Energy balance of the process

Timeline

-Complete mid-semester presentation by February 27th, 2018
-Complete deliverables over the course of the spring semester with the final report finished by April 17th, 2018

Section 3
Market and Competitive Analysis

3.1 Market Analysis

3.1.1 Energy

The United States consumed approximately 97.18 quadrillion BTUs of energy in 2016, 28.43 quadrillion of which were natural gas.

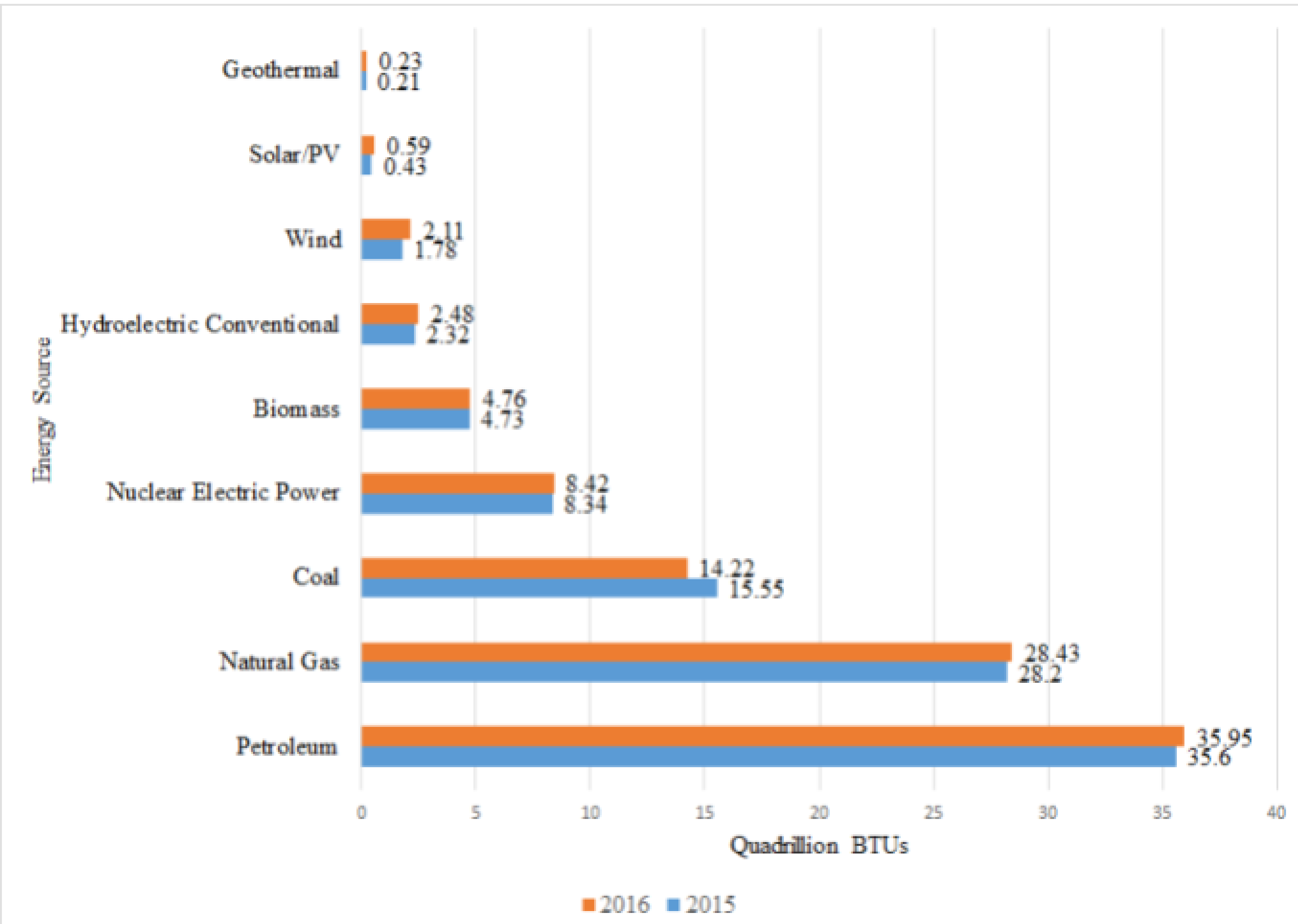


Figure 3.1. Energy consumption in the US in quadrillion British thermal units by source.

For a project of this scale, finding customers to buy the electricity generated from the combustion process should not be an issue. For the natural gas required in the combustion process, there are many distributors in the US. Atmos Energy, headquartered in Dallas, Texas, is one of the largest proprietors of natural gas, and is conveniently located so as to minimize transportation fees. Its location is advantageous for this project because, in the United States, the region with the largest energy consumption per capita is the South, primarily Louisiana at 912 million BTUs.

Table 3.1. US Energy Production and Consumption Rankings from the EIA.

US Energy Consumption Rankings per capita			US Energy Production Rankings		
Rank	State	Consumption per Capita (million BTUs)	Rank	State	Total Production (trillion BTUs)
1	Louisiana	912.2	1	Texas	1554.3
2	Wyoming	892.9	2	Florida	812.4
3	Alaska	840.3	3	Pennsylvania	733
4	North Dakota	802.8	4	California	679.1
5	Iowa	478.8	5	Illinois	637.9
6	Texas	470.2	6	Alabama	488
7	Nebraska	450.5	7	New York	458.1
8	South Dakota	447	8	Georgia	454.9
9	Indiana	430.4	9	North Carolina	448.6
10	West Virginia	420.9	10	Ohio	407.3
11	Oklahoma	417.4	11	Washington	384.8
12	Alabama	393.4	12	Michigan	384.6
13	Kentucky	390	13	Arizona	371.1
14	Montana	379.3	14	Louisiana	364
15	Mississippi	378.9	15	Indiana	347.4

This makes the Gulf Coast area ideal for a process of this nature. Texas holds the highest rank at 20.6% of total US energy production. This means that the energy produced by this process can easily be sold to the grid. However, in this region, electricity can only be sold for around 8 cents per kilowatt-hour, well below the US average retail price of 10.41 cents per kilowatt-hour. Nonetheless, the statistics look good in the long run, as electricity prices have slowly been rising each year, from 9.74 cents in 2008 to 10.54 cents in 2017 per kilowatt-hour on average.

Table 3.2. Annual totals for average electricity prices for ultimate customers in cents per kilowatt-hour.

Period	Residential	Commercial	Industrial	Transportation	All Sectors
Annual Totals					
2008	11.26	10.26	6.96	10.71	9.74
2009	11.51	10.16	6.83	10.86	9.82
2010	11.54	10.19	6.77	10.56	9.83
2011	11.72	10.24	6.82	10.46	9.9
2012	11.88	10.09	6.67	10.21	9.84
2013	12.13	10.26	6.89	10.55	10.07
2014	12.52	10.74	7.1	10.45	10.44
2015	12.65	10.64	6.91	10.09	10.41
2016	12.55	10.43	6.76	9.63	10.27
2017	12.9	10.68	6.91	9.67	10.54

3.1.2 Nitrogen

There exist many industrial applications for high purity nitrogen gas. One of these is the aerospace and aircraft industry. The implementation of nitrogen gas in this area includes aircraft tyre inflation. High purity nitrogen is required for these tyres lest they become deflated due to oxygen permeation. It also reduces the risk of fire hazards (Nitrogen).

Other utilizations of nitrogen gas in the aerospace industry include, but are not limited to, inflatable slides and life rafts, fuel tank inerting, and shock-absorbing springs that dampen aircraft landing loads. This is largely due to pure nitrogen's non-reactiveness and inflammability.

In the automotive industry, nitrogen gas is used to make sodium azide, NaN_3. This chemical decomposes when a car detects that a collision has occurred, releasing the nitrogen into the airbag. Due to its non-explosive nature, it is the key factor in saving the lives of drivers and front-seat passengers in many automobile accidents ("How").

It is also used in welding alongside other welding gases to make frames, chasses, mufflers, and other components which require a proper atmosphere to produce adequate welds.

In the chemicals industry, nitrogen is used as a pressurizing gas due to its tendency to not react with many other gases. It can help propel liquids through pipelines and is the primary gas used to shield oxygen-sensitive materials from the air. These encapsulate just some of the many applications of nitrogen gas. Some more industries include foods and beverages, healthcare, energy, metallurgy, and pharmaceuticals ("Buy").

The primary source of revenue for this project is in fact the large quantity of high purity gaseous nitrogen produced in each of the three different air separation processes. This nitrogen should be simple enough to sell to whichever industry requires it. There is also an Air Liquide location in Houston, Texas, which can be directly supplied to depending on production rates.

Nitrogen gas can be sold at a rate of around 0.5 cents per liter. Since the density of nitrogen at standard temperature and pressure is 1.25 g/L, this process would generate a revenue of $400 per kg of nitrogen produced in the concentrated nitrogen stream. The rest of the nitrogen is contained in the enriched oxygen stream at concentrations of either 64, 47, or 5 mol.%.

3.1.3 Carbon Dioxide

Although this project does not encapsulate carbon dioxide sequestration, the combustion process produces a large quantity of flue gas which contains mainly CO_2, steam, and trace amounts of impurities such as NO_x. Since this project aims to reduce NO_x emissions, the main source of atmospheric contamination is CO_2.

Carbon dioxide has a wide range of industrial uses, ranging from refrigeration and cooling to enhancing the yield of plant products in greenhouses (CO2). A prime customer for the CO_2 generated by the combustion process is in the extraction of crude oil from wells. Along the Gulf Coast lies a multitude of oil wells, both onshore and offshore ("Map"). These wells require consistent supplies of carbon dioxide to not only maintain pressure within rock formations drilled into, but also to render the extracted oil less viscous, allowing for simpler withdrawal.

3.2 Competitive Analysis

At the present time, the majority of the world's electricity comes from coal-fired power plants, which provide approximately 39.3% of the total. Natural gas accounts for 22.9% of the world's electricity. (Hanania). There are too many power plants in the US alone to name, so the focus of competition will remain in states along the Gulf Coast. The largest producer of electricity using natural gas is Sabine in Orange County, Texas at a capacity of 2,051 MW. However, this is a commercial-scale plant and uses air to provide the necessary oxygen required for combustion. The process described in this report utilizes a stream of enriched oxygen, either 36, 53, or 95 mol.%, generated from the air separation units and is pilot-scale. At the moment, there are no oxy fuel combustion plants, planned or otherwise, in the United States.

There were a few pilot plants located overseas that examined the feasibility of oxy fuel combustion including the inspiration for this project: Linde's Schwarze Pumpe in Spremberg, Germany. The key difference between this plant and the one proposed in this paper is that the Schwarze Pumpe utilized lignite, a form of coal with low heat content, instead of natural gas. It consisted of one 30 MW-capacity unit. The Schwarze Pumpe was met with a number of roadblocks, including uproar from environmental activists attempting to cordon off coal supply routes and mines. In May of 2014, the plant was decommissioned.

In these times, where CO_2 reduction is not a priority, oxy fuel technology does not appear to be competitive. However, it still remains a viable alternative in carbon capture, and may be economical in the future.

Section 4
Preliminary Process Synthesis

4.1 Overall Process

Historically, power plants have used streams of dry air, 21% oxygen by mole, alongside a fuel source to provide the O_2 necessary for combustion. Due to the excess amount of nitrogen in this air stream, the effluent generated by this process contains a large amount of toxic gases such as NO_x and SO_x. The Linde Group fashioned a similar process to save energy and increase efficiency while also reducing the amount of nitrous and sulfur oxides. This process is shown in Figure 4.1.

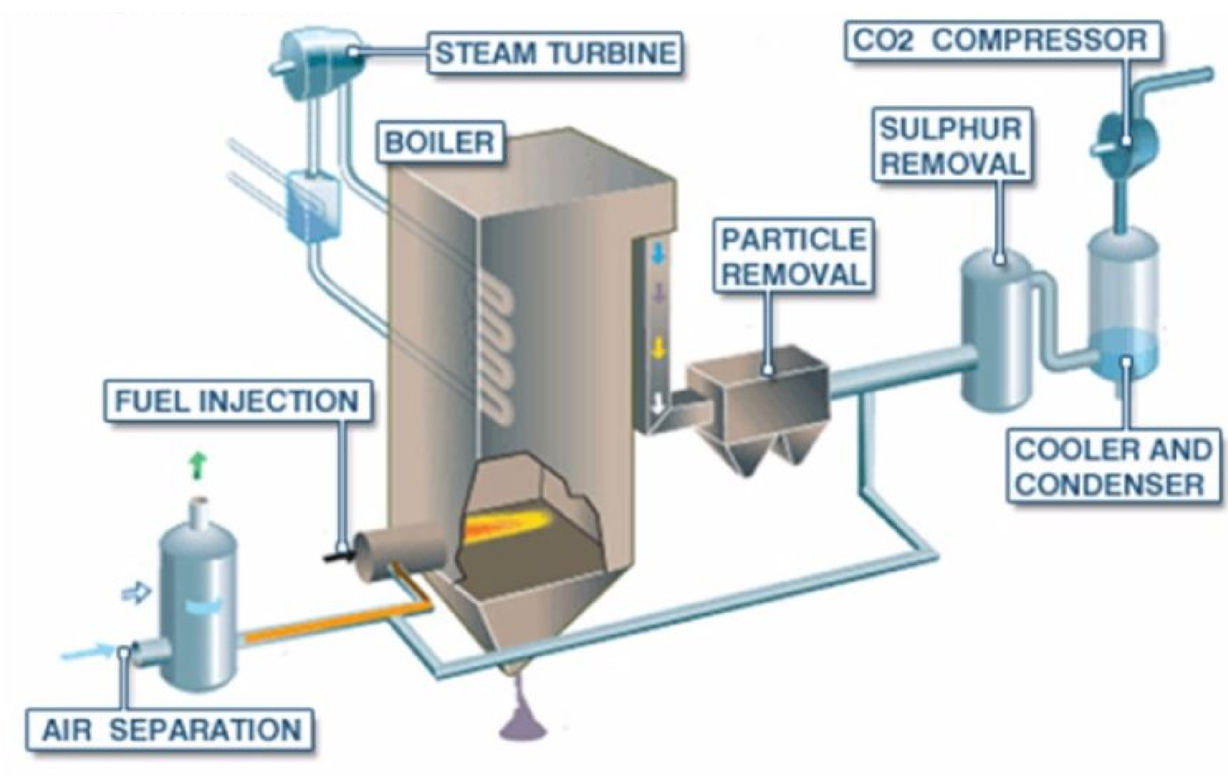


Figure 4.1. Overall process diagram

For the purposes of this project, the combustion will not be rigorously modeled and will be treated as a black box.

The Linde process uses lignite, a form of coal. This project aims to emulate this except in that it will use natural gas instead. The reasoning behind this is that combustion using natural gas reduces CO_2 in the flue gas by up to 60 percent when compared to plants that use coal.

4.2 Scenarios

Air Products and Chemicals, Inc. developed multiple patents for cryogenic air separation that produce oxygen-rich streams given a feed of dry air. The first of these patents, shown in Figure 4.2 and invented by Robert M. Thorogood, Thomas M. Roden, and Jeffrey A. Hopkins, details the process to make a 53 mol.% oxygen stream (Thorogood).

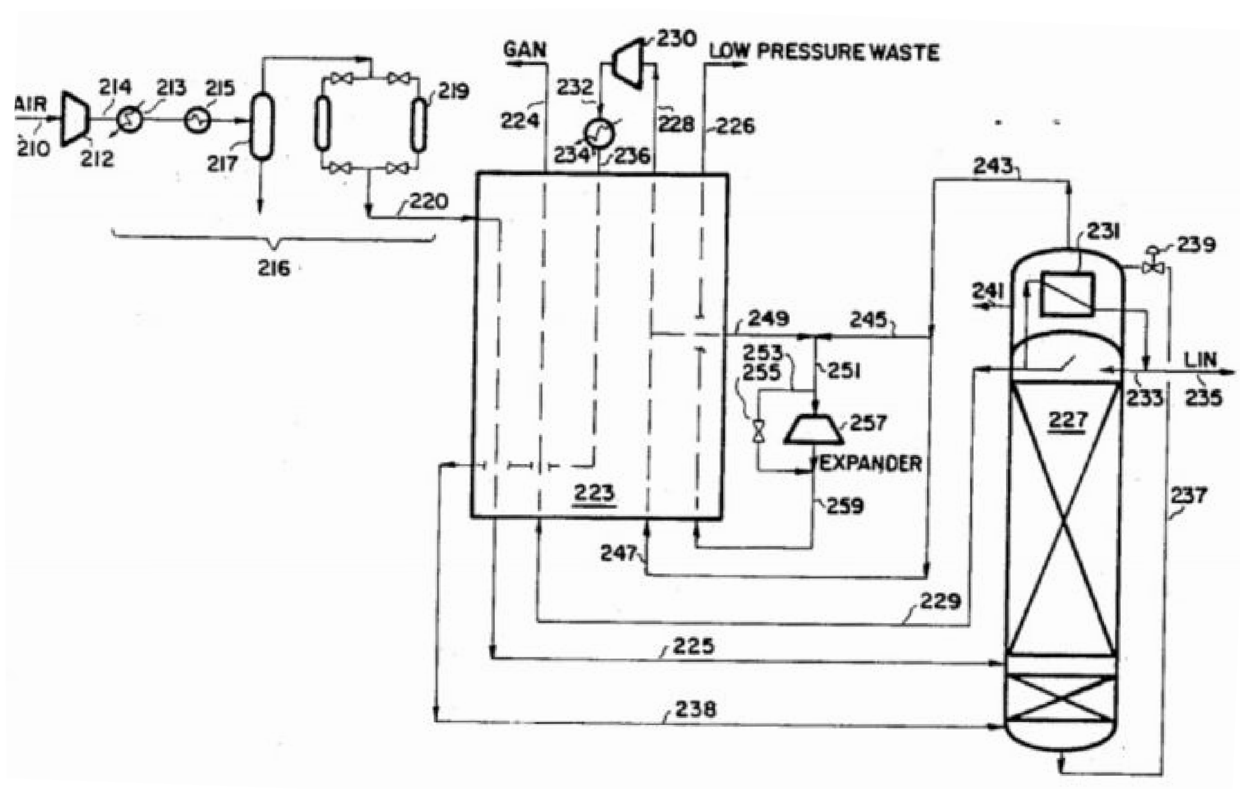


Figure 4.2. Patent for 53% oxygen stream (Low Pressure Waste).

The main products of this process are two enriched nitrogen streams (LIN and GAN on the diagram). The "waste" stream is vented to the atmosphere. However, this project aims to utilize this waste stream and burn an injection of natural gas in a furnace with it. The nitrogen streams are unnecessary and can be sold or vented to the atmosphere.

Another case that will be analyzed is similar to this, except for the fact that the recycle stream that goes through the compressor (230) is removed. This produces an oxygen stream with a concentration of 36 mol.%.

The third and final case that will be covered in this report comes from another Air Products and Chemicals, Inc. patent, shown in Figure 4.3 (Brostow).

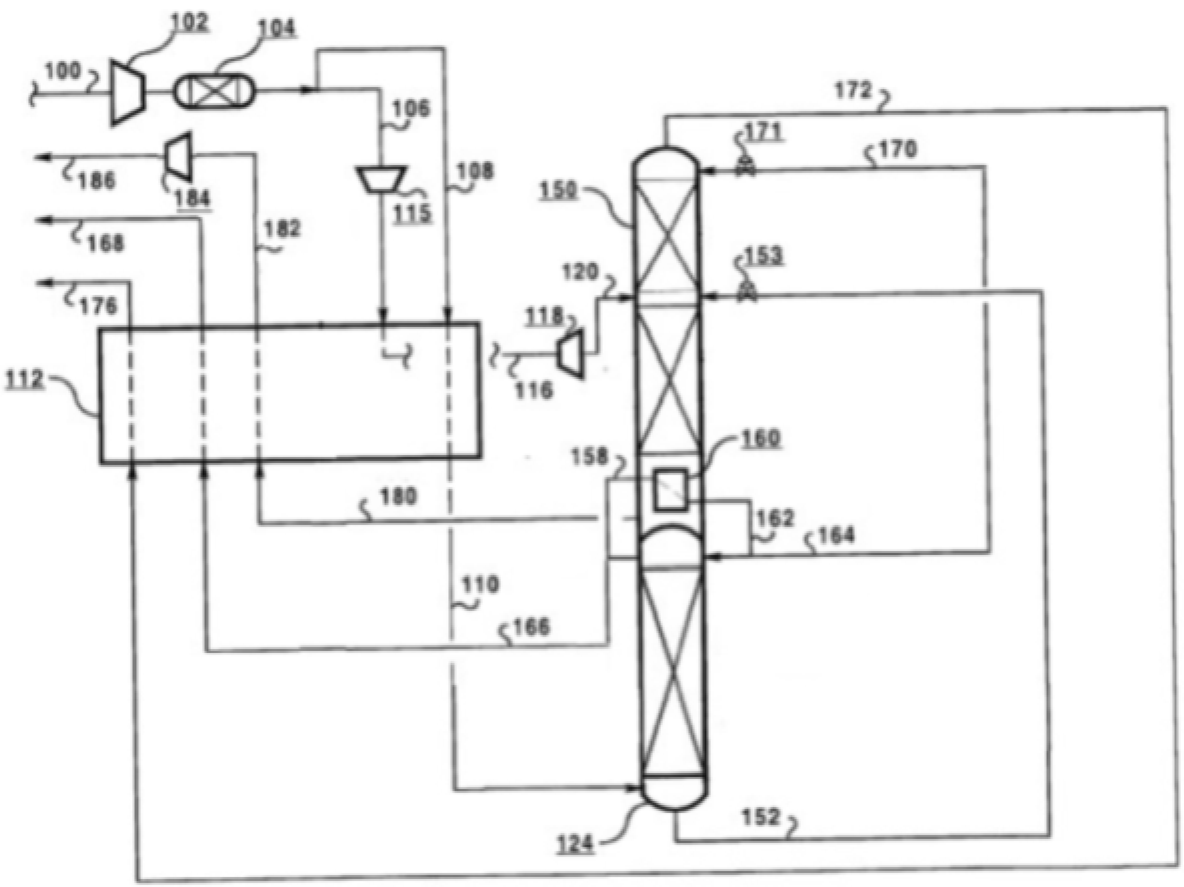


Figure 4.3. Patent for 95% oxygen stream (186)

This patent, invented by Adam Brostow and Donn Herron, utilizes a double-column setup. The lower column is run at a high pressure and sends streams to the low pressure column above it. Stream 186 is the one that will be used in the combustion process while product streams 168 and 176 are nitrogen-rich and can be sold or vented to the atmosphere.

Section 5
Assembly of Database

5.1 Thermophysical Property and Price Data

The primary components of this process are listed in Table 5.1. This includes components in the combustion section, such as methane, carbon dioxide, and water, although the combustion is not modeled rigorously in this report. Methane comprises the largest portion of natural gas at 93.9 mol.% ("Chemical"). The remainder is primarily ethane at 4.2 mol.% with components such as nitrogen, carbon dioxide, propane, and higher order hydrocarbons taking up less than 1% of the total composition of natural gas. The gross heating value of natural gas was discovered to be around 38.7 MJ/m^3.

Table 5.1. Thermophysical properties of key components

Component	Cp (KJ/kg-K)	Boiling Point (K)	Molecular Weight (g/mol)	Price ($)	ΔHvap (KJ/kg)	ΔHcombust (KJ/kg)	Density, l (kg/m^3)	Density, v (kg/m^3)	Comments
Air	1.006	78.8	28.96	~0	201.9	N/A	870	1.276	Feed stream
Carbon Dioxide	0.849	194.7	44	N/A	379.5	N/A	1101	1.977	In flue gas
Ethane	1.715	184.9	30.1	0.0045/f ^{3}	N/A	-51,800	546.5	1.36	Secondary component of natural gas
Methane	2.23	111.7	16.04	0.0045/f ^{3}	N/A	-55,530	422.6	0.656	Primary component of natural gas
Nitrogen	1.04	77.4	28.01	N/A	199	N/A	808.4	1.25	In product stream from air separation
Oxygen	0.92	90.2	32	N/A	213	N/A	1142	1.429	In product stream from air separation
Water	4.184	373.1	18	~0	2030	N/A	1000	0.804	Cooling water, steam in flue gas

5.2 Toxicity Data

Kiriishi, et. al analyzed flame temperatures and NO_x and SO_x production of oxy fuels based on oxygen enrichment. For an air ratio of 1.1, a furnace temperature of 1200 C, and a fuel-gas ratio of 2 m^3 N/m^3 N-fuel, the NO_x emissions are depicted in figure 5.1 (Kiriishi).

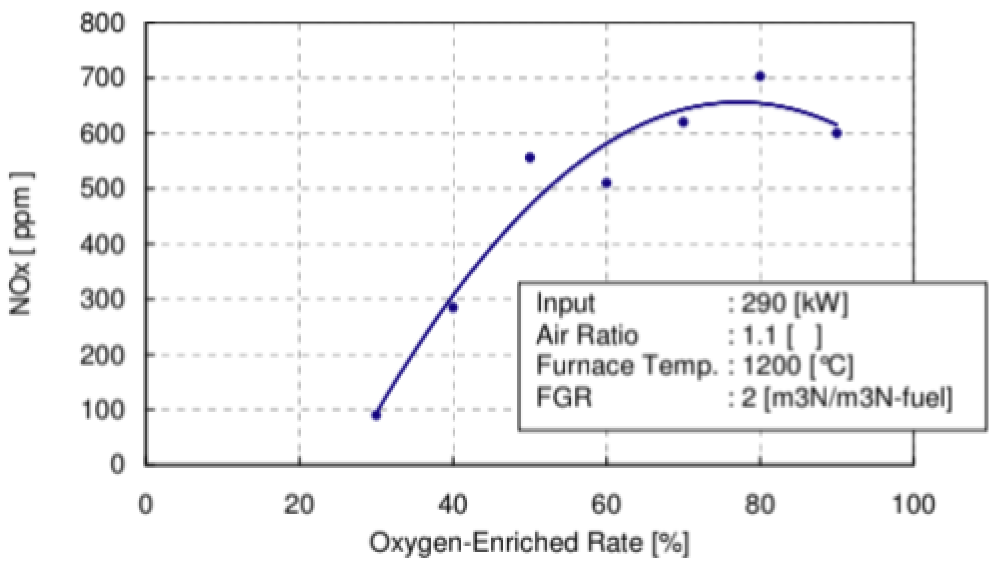


Figure 5.1. NO_x emissions data based on oxygen enrichment.

There exists a very clear parabolic shape on the graph, indicating a suboptimal enrichment rate and two optimal enrichment rates. According to Kiriishi, under these conditions, a stream of 70-80% oxygen produces the most NO_x, even more than streams with lower oxygen concentrations. The graph comes back down after this peak, indicating that after the threshold, NO_x production will decrease with oxygen enrichment.

For this project, the upper and lower limits of oxygen concentration, namely 95% and 36% respectively, Kiriishi indicates that the process will yield positive results in terms of toxin production while the middle value of 53% oxygen enrichment may or may not produce too much NO_x.

Section 6
Process Flow Diagram and Material Balance

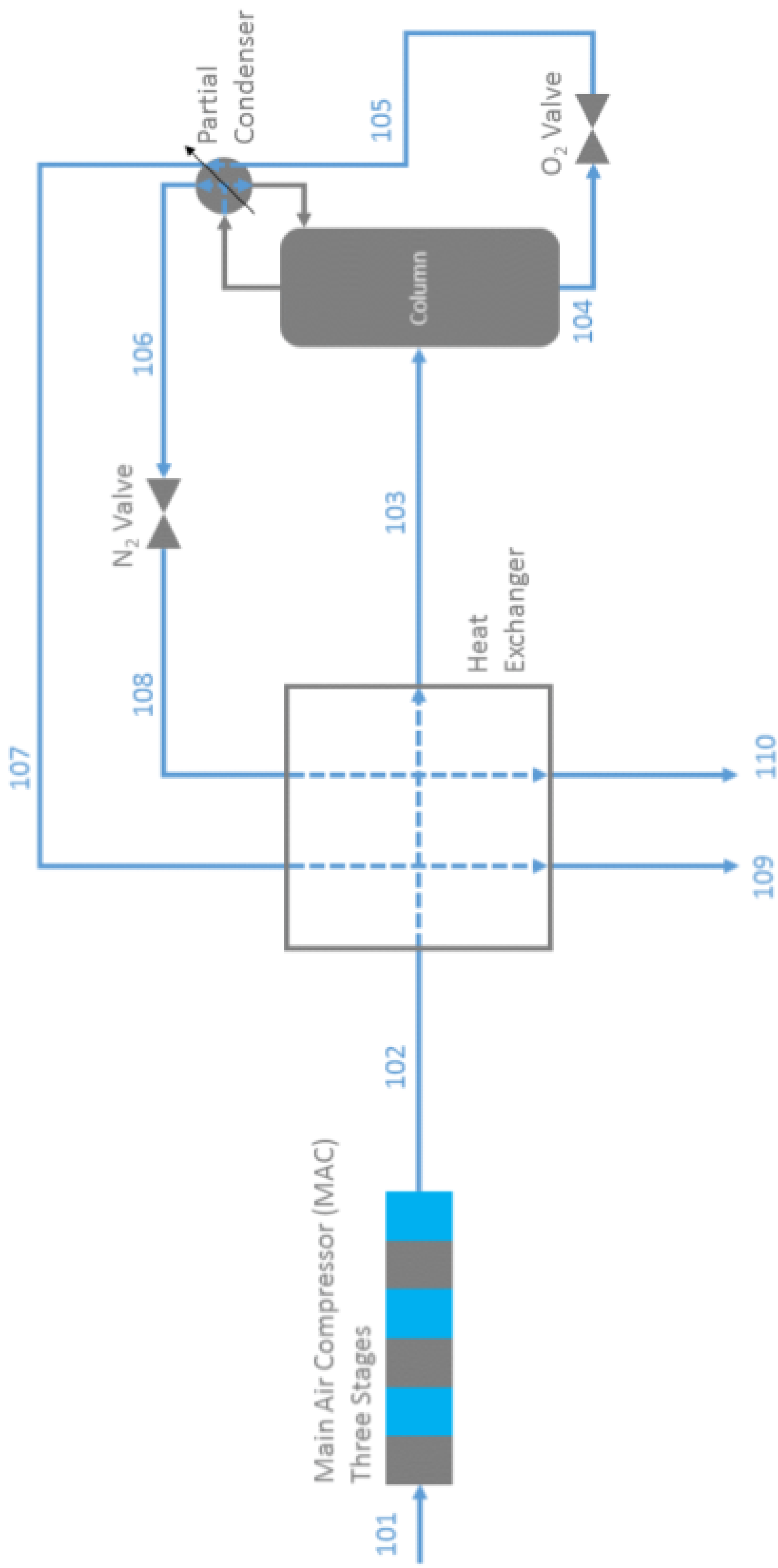


Figure 6.1. Section 100: 36% Product Oxygen Concentration

Table 6.1. Stream table for 36% Oxygen case.

Stream	**101**	**102**	**103**	**104**	**105**
Temperature (F)	85	90	-273	-278	-310
Pressure (psig)	0	83.3	78.3	78	4.3
Vapor Fraction	1	1	1	0	0.19
Mass Flow (lb/hr)	30,212	30,212	30,212	178,576	178,576
Mole Flow (lbmol/hr)	10,472	10,472	10,472	6,063	6,063
Volume Flow (cuft/hr)	4,160,000	631,000	196,000	3,580	95,100
Composition (Mol %)					
Oxygen	0.21	0.21	0.21	0.362	0.362
Nitrogen	0.79	0.79	0.79	0.638	0.638
Stream	**106**	**107**	**108**	**109**	**110**
Temperature (F)	-285	-278	-301	87.5	88.6
Pressure (psig)	76.3	4.3	4.3	-0.7	-0.7
Vapor Fraction	1	1	1	1	1
Mass Flow (lb/hr)	123,544	178,576	123,544	178,576	123,544
Mole Flow (lbmol/hr)	4,409	6,063	4,409	6,063	4,409
Volume Flow (cuft/hr)	77,200	605,000	381,000	2,540,000	1,850,000
Composition (Mol %)					
Oxygen	0.001	0.362	0.001	0.362	0.001
Nitrogen	0.999	0.638	0.999	0.638	0.999

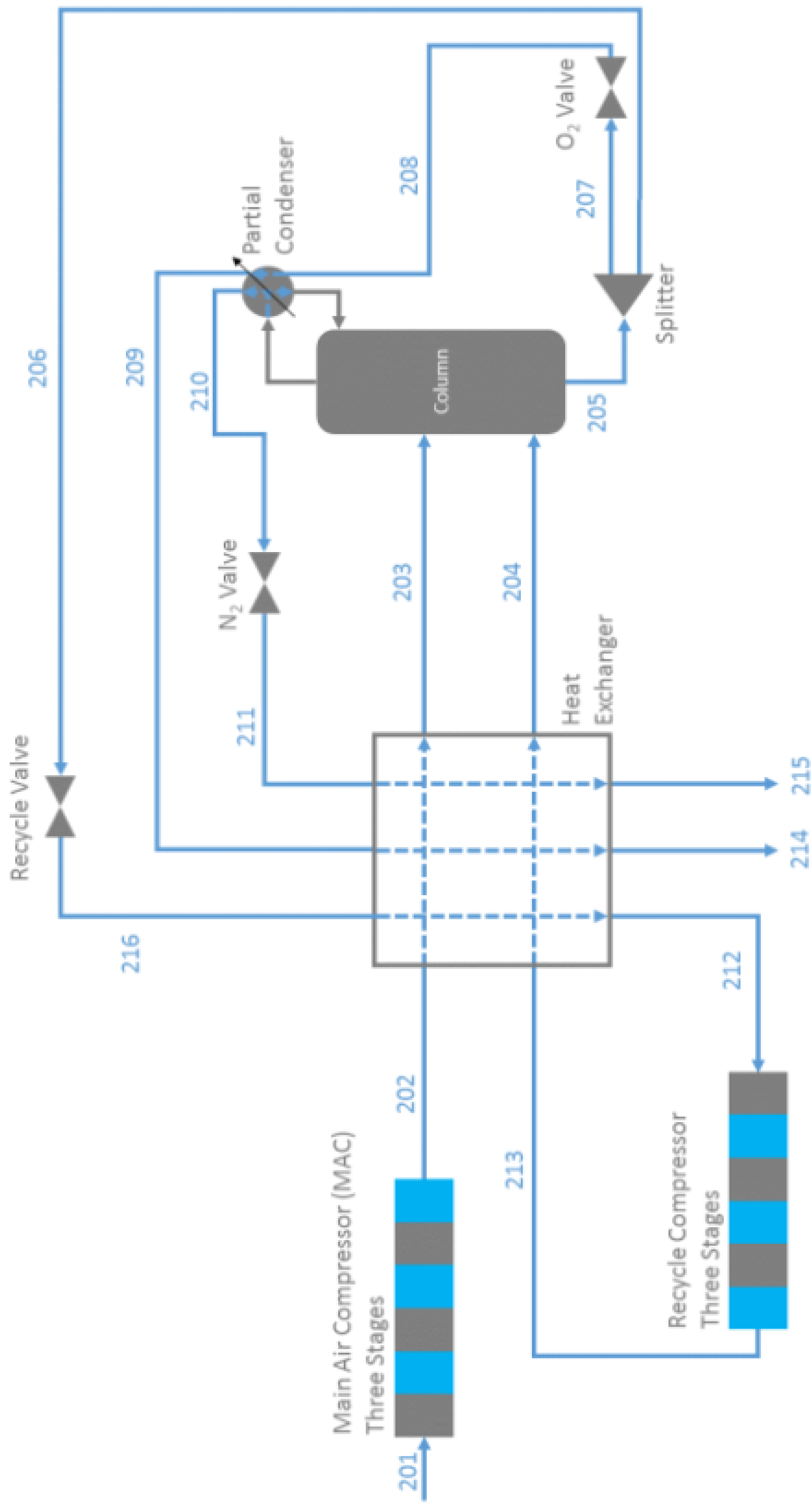


Figure 6.2. Section 200: 53% Product Oxygen Concentration

Table 6.2. Stream table for 53% Oxygen case.

Stream	201	202	203	204	205	206
Temperature (F)	85	90	-269	-256	-265	-265
Pressure (psig)	0	114	112	113	113	113
Vapor Fraction	1	1	0.98	1	0	0
Mass Flow (lb/hr)	362,544	362,544	362,544	149,388	298,776	149,388
Mole Flow (lbmol/hr)	12,566	12,566	12,566	4,960	9,921	4,960
Volume Flow (cuft/hr)	5,000,000	575,000	164,000	72,000	5,870	2,940
Composition (Mol %)						
Oxygen	0.21	0.21	0.21	0.528	0.528	0.528
Nitrogen	0.79	0.79	0.79	0.472	0.472	0.472

Stream	207	208	209	210	211
Temperature (F)	-265	-306	34.7	-306	-299
Pressure (psig)	113	5.3	5.3	5.3	5.3
Vapor Fraction	0	0.232	1	0.232	1
Mass Flow (lb/hr)	149,388	149,388	149,388	149,388	213,156
Mole Flow (lbmol/hr)	4,960	4,960	4,960	4,960	7,606
Volume Flow (cuft/hr)	2,940	92,800	1,320,000	96,900	630,000
Composition (Mol %)					
Oxygen	0.528	0.528	0.528	0.528	0.003
Nitrogen	0.472	0.472	0.472	0.472	0.997

Stream	212	213	214	215	216
Temperature (F)	88	90	85	88	-306
Pressure (psig)	3.3	115	3.3	3.3	5.3
Vapor Fraction	1	1	1	1	0.232
Mass Flow (lb/hr)	149,388	149,388	149,388	213,156	149,388
Mole Flow (lbmol/hr)	4,960	4,960	4,960	7,606	4,960
Volume Flow (cuft/hr)	1,620,000	225,000	1,610,000	2,480,000	92,800
Composition (Mol %)					
Oxygen	0.528	0.528	0.528	0.003	0.528
Nitrogen	0.472	0.472	0.472	0.997	0.472

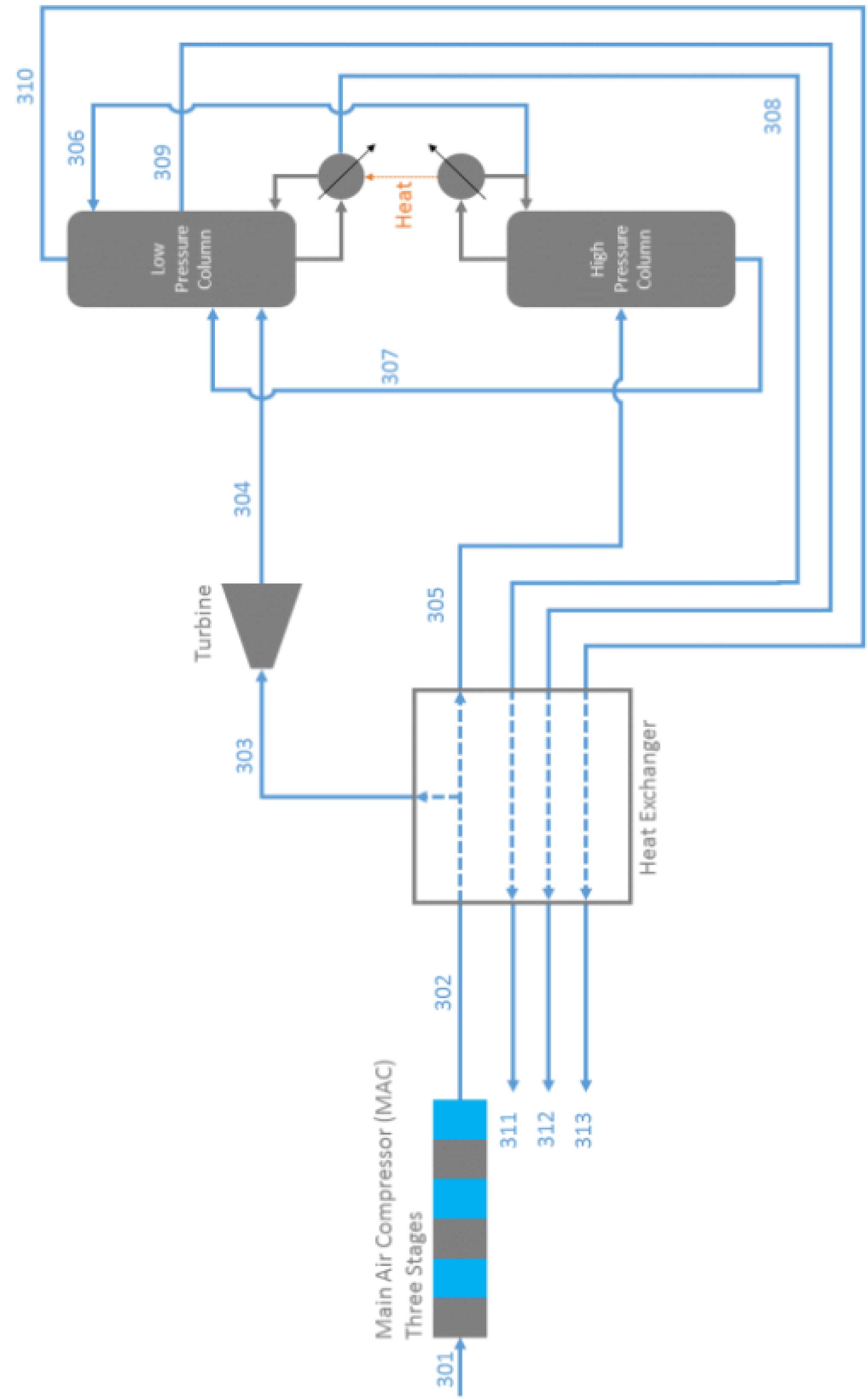


Figure 6.3. Section 300: 95% Product Oxygen Concentration

Table 6.3. Stream table for 95% Oxygen case.

Stream	301	302	303	304	305
Temperature (F)	85	95	-150	-244	-277
Pressure (psig)	0	87.3	87.3	10.3	87.3
Vapor Fraction	1	1	1	1	0.59
Mass Flow (lb/hr)	381,625	381,625	76,325	76,325	305,300
Mole Flow (lbmol/hr)	13,228	13,228	2,646	2,646	10,582
Volume Flow (cuft/hr)	5,260,000	770,000	83,300	239,000	104,000
Composition (Mol %)					
Oxygen	0.21	0.21	0.21	0.21	0.21
Nitrogen	0.79	0.79	0.79	0.79	0.79
Stream	**306**	**307**	**308**	**309**	
Temperature (F)	-285	-279	-289	-308	
Pressure (psig)	77.3	78.6	12.6	9	
Vapor Fraction	0	0	0	1	
Mass Flow (lb/hr)	82,911	222,389	74,699	128,043	
Mole Flow (lbmol/hr)	2,957	7,625	2,350	4,500	
Volume Flow (cuft/hr)	1,880	4,530	1,100	291,000	
Composition (Mol %)					
Oxygen	0.007	0.29	0.947	0.111	
Nitrogen	0.993	0.71	0.053	0.889	
Stream	**310**	**311**	**312**	**313**	
Temperature (F)	-312.6	80	80	80	
Pressure (psig)	8.3	8.3	9	8.3	
Vapor Fraction	1	1	1	1	
Mass Flow (lb/hr)	178,884	74,699	128,043	178,884	
Mole Flow (lbmol/hr)	6,378	2,350	4,500	6,378	
Volume Flow (cuft/hr)	413,000	591,000	1,100,000	1,600,000	
Composition (Mol %)					
Oxygen	0.009	0.947	0.111	0.009	
Nitrogen	0.991	0.053	0.889	0.991	

Section 7
Process Description

7.1 Overall Process

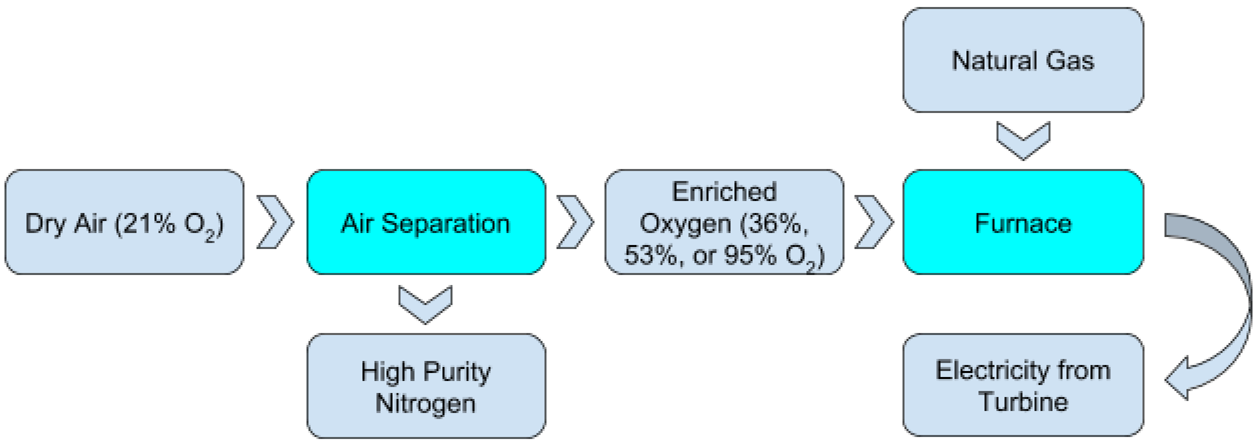


Figure 7.1. Overall process flowchart

The overall process can be broken down into two stages: the air separation and the combustion sections. There are three cases for the air separation. The first involves a single column without a recycle stream, which outputs an enriched oxygen stream of 36 mol.%. The second case adds the recycle stream to this single column process to produce a final oxygen concentration of 53 mol.%. The last case uses two columns: a high pressure and a low pressure one. The oxygen concentration in the enriched stream in this case is 95 mol.%. In all three scenarios, the exiting enriched oxygen stream is fed into a boiler and is burned with natural gas, creating steam and carbon dioxide. This flue gas can be recycled back into the system to reduce the flame temperature. For the purposes of this project, the combustion portion of the process will not be rigorously modeled.

7.2 36% Case

Figure 6.1 details the air separation process for the 36% O_2 case. A stream of air (21 mol.% oxygen and 79 mol.% nitrogen) is fed to a three-stage compressor. This compressor is comprised of three intercoolers which saves energy by allowing cooling between stages. This compressed air stream is then put through a multi-stream heat exchanger, which acts as a medium for various streams throughout the process to exchange heat and reach desired temperatures. Because the required separation cannot occur at ambient temperatures, the heat exchanger lowers the temperature of the compressed air stream to cryogenic temperatures. This cold, compressed air is then fed into the column, which separates the air into two enriched streams. The bottoms product is the stream used in the oxy fuel combustion section and has a composition of 36% oxygen and 64% nitrogen by mole. The distillate contains high purity nitrogen (99.9%) that can be sold for revenue. These streams are then depressurized and fed back into the multi-stream heat exchanger to return their temperatures to ambient conditions.

7.3 53% Case

Figure 6.2 portrays the air separation diagram for the 53% O_2 scenario. Similar to the 36% case, a stream of air is fed to a three-stage compressor and then into the column. However, after the separation, half of the bottoms product, the enriched oxygen stream, is split off from the product stream and recycled back into the column after it is compressed and cooled again. The product stream contains 53% oxygen and 47% nitrogen by mole. This stream enters the combustion section as the enriched oxygen stream. The distillate stream contains high purity nitrogen (99.7%) which can be sold. This air separation process is almost exactly the same as the 36% case with the key difference being the split recycle stream which drives up the final oxygen concentration by about 17 mol.%.

7.4 95% Case

The third and final scenario is the case where two columns with different operating pressures are utilized to produce an enriched oxygen stream of 95 mol.%. This process is depicted in Figure 6.3. Again, a stream of dry air is fed into a three-stage compressor and then through the multi-stream heat exchanger, which lowers the temperature of the stream to cryogenic values. After this, 20% of it enters a high pressure column, operating at a pressure of 77.3 psi. The remaining 80% of the initial compressed air stream splits off and enters an expander, recovering some power, and is then fed into the bottom of the low pressure column, which operates at a pressure of 8.3. The distillate from the high pressure column is an enriched nitrogen stream (99.3%) which is recovered and fed to the top of the low pressure column. These two columns are not separate; they are stacked on top of one another with the low pressure one on top. In essence, this means that the duty from the condenser of the high pressure column must equal that of the reboiler of the low pressure column. The bottoms product of the high pressure column is simply a liquid air stream with 21% oxygen. This stream is recovered and fed into the low pressure column at a stage below the enriched nitrogen stream from the high pressure column and above the air stream from the expander. The bottoms product of the low pressure column is the enriched oxygen stream which has an oxygen concentration of about 95%. The distillate contains an enriched nitrogen stream (99.1%) which can be sold. There is another product stream that comes off of the low pressure column which has a composition of 89%. This purity is far too low to sell for revenue, so it will be vented to the atmosphere. These three streams return to the multi-stream heat exchanger to bring their temperatures to ambient conditions.

Section 8
Energy Balance and Utility Requirements

The cryogenic nature of this process emphasized the importance of minimizing lost heat, minimizing utility costs. The entirety of the input for internal cooling was supplied by the three-stage compressor and its cooling water. Tables 8.1, 8.2, and 8.3 show the overall system energy balances for each oxygen concentration case. Much of the cooling for input streams was done in the heat exchangers for each case, cooling the input streams and hearing the outlet streams, as shown in Section 6.

Cooling water had a temperature change of 25 ºF. Streams 101, 201, and 301 all entered at ambient temperature, assumed to be 85 ºF in the gulf coast. Streams 101 and 201 became 90 ºF, while stream 301 became 95 ºF. This is a small temperature change; much of the energy was used to compress the streams. Stream 101 was compressed from 0 psig to 83.3 psig. Stream 201 was compressed from 0 psig to 114 psig. Stream 301 was compressed from 0 psig to 87.3 psig. All of this data is shown in Tables 6.1, 6.2, and 6.3. For additional cooling in the 95% oxygen case, an expander was used. This generated about 340 kW of power while cooling stream 303 from -150 ºF to -244 ºF. The pressure reduced from 87.3 psig to 10.3 psig. Overall, the 36% oxygen case had about 9.8 MW in and out. The 53% oxygen case had about 18.4 MW in and out. The 95% oxygen case had about 14.2 MW in and out. The 53% oxygen case had substantially more because the change in pressure from ambient to column was much higher for this case. In order to achieve the goal of 30 net MW, each case must generate 30 MW + the energy balance of the air separation unit. This energy will be generated in the boiler and steam turbine, which the product streams feed. For startup, liquid nitrogen will be used. The process will be cooled slowly in order to reduce metal fatigue. Alternatively, the process could start as normal, and the compressor would cool the system. However, this would take much more time and energy.

Tables 8.1, 8.2, and 8.3 show the summarized input and outlet streams for each process as a whole. Streams 101, 102, and 103 are dry air that entered the three-stage compressor. The compressor increased enthalpy by compressing, but its cooling water also decreased the enthalpy by roughly the same amount for all three cases. In Table 8.1, streams 109 and 110 were the product streams exiting the heat exchanger. In Table 8.2, streams 214 and 215 were the product streams for the system exiting the heat exchanger. In Table 8.3, streams 311, 312, and 313 were the product streams exiting the heat exchanger. Streams 110, 215, and 313 were the nitrogen product streams, all with at least 99% purity. Streams 109, 214, and 311 were the oxygen product streams, with purities depending on the case. Stream 312 was the waste stream in the 95% oxygen case. Because the exit temperatures and pressures were similar to the entrance temperatures and pressures, the enthalpies of the product streams were similar to those of the feed streams for the system. Any discrepancies were fully accounted for in the difference in enthalpies between the compressing and cooling in the three-stage compressor.

Table 8.1. Total system energy balance for 36% Oxygen case.

Stream In		Enthalpy Flow (kW)	Stream Out	Enthalpy Flow (kW)
101		163	109	126
			110	101
Total		**163**	**Total**	**227**
Cooling Water		**Compressor (kW)**	**OUT - IN (kW)**	
-9,588	kW	9,652	**0**	
1,300,000	lb/hr			

Table 8.2. Total system energy balance for 53% Oxygen case.

Stream In		Enthalpy Flow (kW)	Stream Out	Enthalpy Flow (kW)
201		196	214	76
			215	165
Total		**196**	**Total**	**241**
Cooling Water		**Compressor (kW)**	**OUT - IN (kW)**	
-18,187	kW	18,233	0	
2,480,000	lb/hr			

Table 8.3. Total system energy balance for 95% Oxygen case.

Stream In		Enthalpy Flow (kW)	Stream Out	Enthalpy Flow (kW)
301		203	311	10
			312	20
			313	29
Total		**203**	**Total**	**59**
Cooling Water		**Compressor (kW)**	**Expander (kW)**	**OUT - IN (kW)**
-13,762	kW	13,958	-340	0
1,870,000	lb/hr			

Section 9
Equipment List and Unit Descriptions

Section 9.1 95% Case

Main Air Compressor

Unit ID: Main Air Compressor (MAC)
Type: Multi-stage Compressor
Material: Carbon Steel
Specification Sheet: Page 69
Costing Data: Page 76

Temperature: 95 °F
Pressure: 87.3 psig
Work: 18,700 hp

The multi-stage air compressor was designed with ASPEN. The compressor needed 2 intercoolers in between stages to save work. The compressor had three stages with the 2 intercoolers. The pressure drop from one cooler to the next was 3 psi. The temperature at the outlet of the coolers was set to 95°F to avoid melting the compressor. Air was the feed stream to the compressor. The outlet pressure from the multistage compressor was 87.3 psig. The total work done by the compressor was 18,700 horsepower (13.96MW) and the cooling duty was -13.76MW. There were 13,200 lbmol/hr and 382,000 lb/hr going through the compressor.

Brazed Aluminum Heat Exchanger

Unit ID: Heat Exchanger
Type: Plate-fin
Material: Brazed Aluminum
Duty: 12.5 MW
Specification Sheet: Page 70
Costing Data: Page 76

LMTD (Duty/UA): 11.5 °F
Pressure: 8-87 psig
UA: 3,720,000 Btu/hr-R

Multi-stream heat exchanger was designed with ASPEN. The heat exchanger was a countercurrent plate-fin heat exchanger that used brazed aluminum as the material. The total duty of the heat exchanger was -12.5 MW. The heat exchanger was modeled on ASPEN as two separate heat exchangers as was recommended, but in reality it was one heat exchanger. The UA was 3.72*10^6 BTU/hr-R and the LMTD (log mean temperature difference) is 11.5°F. The heat exchanger was used to bring the feed streams to cryogenic temperatures as they moved towards the distillation columns or the turbine and was also used to bring the product oxygen, nitrogen, and waste streams to ambient conditions. There were 26,500 lbmol/hr and 763,000 lb/hr that go through the heat exchanger. Manufacturers can design the brazed aluminum heat exchangers to have pinches less than 1℃ ("Brazed").

Turbine

Unit ID: Turbine
Type: Isentropic
Material: Stainless Steel
Specification Sheet: Page 72
Costing Data: Page 76

Temperature: -244 °F
Pressure: 10.3 psig
Work: -0.48MW

The turbine was designed with ASPEN. The turbine was an isentropic turbine with an isentropic efficiency of 0.9. The work required for the turbine was -0.48MW. The outlet temperature from the turbine was 10.3 psig and the outlet temperature was -244°F. The turbine dropped the temperature and the pressure before stream 304 went into the low pressure column. There were 2650 lbmol/hr and 76,300 lb/hr flowing through the turbine.

Low Pressure Column

Unit ID: Low Pressure Column
Type: Distillation Column
Material: Stainless Steel
Specification Sheet: Page 73
Costing Data: Page 76

Stages: 38
Pressure: 8.3 psig
Diameter: 11.4 feet
Tray Spacing: 1 foot

The Low Pressure column was designed with ASPEN. The Condenser (Top Stage) of the column had a temperature of -313°F and the reflux ratio was set to 0.38 after much trial and error. The Reboiler (bottom stage) had a temperature of -289°F with a duty of 4.1 MW. The boilup ratio waas 2.14. There were 13,200 lbmol/hr and 382,000 lb/hr going through the low pressure column. There were 38 stages for this column with a tray spacing of 1 foot and a diameter of 11.4 feet. The Enriched oxygen stream (Stream 307) was fed on tray 12, the stream from the turbine was fed on tray 18, and the feed from the top of the high pressure column was fed on tray 1. The high oxygen purity product (Stream 308) was a product that comes from tray 38, the high nitrogen purity product (Stream 310) came from tray 1, and the waste stream (Stream 309) came from tray 8. The pressure of the low pressure column was 8.3 psig on stage 1 with a pressure drop of 0.12 psi per tray.

High Pressure Column

Unit ID: High Pressure Column	Stages: 14
Type: Distillation Column	Pressure: 77.3 psig
Material: Stainless Steel	Diameter: 9.9 feet
Specification Sheet: Page 74	Tray Spacing: .75 feet
Costing Data: Page 76	Reflux Ratio: 1.25

The High Pressure column was designed with ASPEN. The Condenser (Top Stage) of the high pressure column had a temperature of -285°F with a duty of -3.97 MW and a reflux ratio of 1.25. The Reboiler (bottom stage) had a temperature of -279°F and a boilup rate of .834. There were 10,600 lbmol/hr and 305,000 lb/hr flowing through the high pressure column. There were 14 trays in the column with a tray spacing of 0.75 feet and a diameter of 9.9 feet. The pressure of the high pressure column was 77.3 psig with a pressure drop of 0.1 psi per stage. The feed from the heat exchanger (Stream 305) is fed on stage 14. The highly purified nitrogen (Stream 306) came out of the high pressure column on stage 1 and the enriched oxygen stream (Stream 307) came out of the column on stage 14. The high and low pressure columns were designed as two separate columns, but in reality they were really one column separated by an interface between the high and low pressure columns. The reboiler of the low pressure column and the condenser of the high pressure column had the same duty in order for this to work. They were extremely close with a difference of 0.1 MW between them.

<u>Section 9.2 36% Case</u>

Main Air Compressor

Unit ID: Main Air Compressor (MAC)
Type: Multi-stage Compressor
Material: Carbon Steel
Specification Sheet: Page 57
Costing Data: Page 77

Temperature: 90 °F
Pressure: 83.3 psig
Work: 12,900 hp

The multi-stage air compressor was designed with ASPEN. The compressor needed 2 intercoolers in between stages to save work. The compressor was three stages with the 2 intercoolers. The pressure changed from 12.97 psig to 37.4 psig to 83.3 psig from stage one of the compressor to stage 3. The temperature at the outlet of the coolers was set to 90°F to avoid melting the compressor. Air was the feed stream to the compressor. The outlet pressure from the multistage compressor was 83.3 psig. The total work done by the compressor was 12,900 horsepower (9.62MW) and the cooling duty was -9.6MW. There were 10,500 lbmol/hr and 302,000 lb/hr going through the compressor.

Brazed Aluminum Heat Exchanger

Unit ID: Heat Exchanger
Type: Plate-fin
Material: Brazed Aluminum
Duty: 8.09 MW
Specification Sheet: Page 58
Costing Data: Page 77
LMTD (Duty/UA): 4.56 °F
Pressure: 4-83 psig
UA: 6,060,000 Btu/hr-R

Multi-stream heat exchanger was designed with ASPEN. The heat exchanger was a countercurrent plate-fin heat exchanger that used brazed aluminum as the material. The total duty of the heat exchanger was 8.09 MW. The UA was $6.06*10^6$ BTU/hr-R and the LMTD was 4.56°F. The heat exchanger was used to bring the feed streams to cryogenic temperatures as they moved towards the distillation columns and was also used to bring the product oxygen and nitrogen to ambient conditions. There were 20,900 lbmol/hr and 604,000 lb/hr went through the heat exchanger. Manufacturers can design the brazed aluminum heat exchangers to have pinches less than 1℃ (“Brazed”).

Column

Unit ID: Column
Type: Distillation Column
Material: Stainless Steel
Specification Sheet: Page 60
Costing Data: Page 77
Stages: 15
Pressure: 76.3 psig
Diameter: 8.74 feet
Tray Spacing: 1 foot

The distillation column was designed with ASPEN. The Condenser (Top Stage) of the column had a temperature of -285°F and the reflux ratio was set to 1.59 after much trial and error. The duty of the condenser was -4.16 MW. The Reboiler (bottom stage) had a temperature of -278°F and a boilup ratio of 1.77. There were 10,500 lbmol/hr and 302,000 lb/hr going through the distillation column. There were 25 stages for this column with a tray spacing of 1 foot and a diameter of 8.74 feet. The feed came from the heat exchanger (Stream 103) and was fed on stage 15. The high oxygen purity product (Stream 104) was a product that came from tray 15 and the high nitrogen purity product (Stream 106) came from tray 1. The pressure of the column was 76.3 psig on stage 1 with a pressure drop of 0.12 psi per tray.

Oxygen Valve

Unit ID: O_2 valve
Type: Valve
Material: Stainless Steel
Specification Sheet: Page 62
Costing Data: Page 77

Temperature: -310 °F
Pressure: 4.3 psig
Vapor Fraction: 0.19

Oxygen valve was designed with ASPEN. The outlet pressure of the oxygen valve was 4.3 psig with a pressure drop of 73.7 psi. The outlet temperature was -310°F with a vapor fraction of 0.19. There were 6060 lbmol/hr and 179,000 lb/hr going through the oxygen valve.

Nitrogen Valve

Unit ID: N_2 valve
Type: Valve
Material: Stainless Steel
Specification Sheet: Page 62
Costing Data: Page 77

Temperature: -301 °F
Pressure: 4.3 psig
Vapor Fraction: 1

Nitrogen valve was designed with ASPEN. The outlet pressure of the nitrogen valve was 4.3 psig with a pressure drop of 72 psi. The outlet temperature was -301°F with a vapor fraction of 1. There were 4410 lbmol/hr and 124,000 lb/hr going through the nitrogen valve.

Section 9.3 53% Case

Main Air Compressor

Unit ID: Main Air Compressor (MAC)
Type: Multi-stage Compressor
Material: Carbon Steel
Specification Sheet: Page 63
Costing Data: Page 77

Temperature: 90 °F
Pressure: 114 psig
Work: 18,000 hp

The multi-stage air compressor was designed with ASPEN. The compressor needed 2 intercoolers in between stages to save work. The compressor was three stages with the 2 intercoolers. The pressure changed from 15.6 psig to 47.8 psig to 114.3 psig from stage one of the compressor to stage 3. The temperature at the outlet of the coolers was set to 90°F to avoid melting the compressor. Air was the feed stream to the compressor. The outlet pressure from the multistage compressor was 114.3 psig. The total work done by the compressor was 18,000 horsepower (13.4MW) and the cooling duty was -13.4MW. There was 5700 lbmol/hr and 164,000 lb/hr going through the compressor.

Recycle Multistage Compressor

Unit ID: Recycle Compressor Three Stages
Type: Multi-stage compressor
Material: Carbon Steel
Specification Sheet: Page 63
Costing Data: Page 77

Temperature: 89.3 °F
Pressure: 115 psig
Work: 6420 hp

The multi-stage recycle compressor was designed with Aspen. The compressor needed 2 intercoolers in between stages to save work. The compressor was three stages with the 2 intercoolers. The pressure changed from 20.1 psig to 52.6 psig to 115.3 psig from stage one of the compressor to stage 3. The temperature at the outlet of the coolers was set to 90°F to avoid melting the compressor. Air was the feed stream to the compressor. The outlet pressure from the multistage compressor was 115.3 psig. The total work done by the compressor was 6420 horsepower (4.79MW) and the cooling duty was -4.8MW. There were 2250 lbmol/hr and 67,800 lb/hr going through the compressor.

Brazed Aluminum Heat Exchanger

Unit ID: Heat Exchanger
Type: Plate-fin
Material: Brazed Aluminum
Duty: 13.6 MW
Specification Sheet: Page 64
Costing Data: Page 77

LMTD (Duty/UA): 14.7 °F
Pressure: 5-115 psig
UA: 3,160,000 Btu/hr-R

Multi-stream heat exchanger was designed with ASPEN. The heat exchanger was a countercurrent plate-fin heat exchanger that used brazed aluminum as the material. The total duty of the heat exchanger was 13.6 MW. The UA was $3.16*10^6$ BTU/hr-R and the LMTD was 14.7°F. The heat exchanger was used to bring the feed streams to cryogenic temperatures as they moved towards the distillation columns and was also used to bring the product oxygen and nitrogen to ambient conditions. 35,100 lbmol/hr and 1,020,000 lb/hr went through the heat exchanger. Manufacturers can design the brazed aluminum heat exchangers to have pinches less than 1℃ (“Brazed”).

Column

Unit ID: Column
Type: Distillation Column
Material: Stainless Steel
Specification Sheet: Page 66
Costing Data: Page 77

Stages: 25
Pressure: 8.3 psig
Diameter 1: 10.9 feet
Diameter 2: 6.49 feet
Tray Spacing: 1 foot

The distillation column was designed with ASPEN. The Condenser (Top Stage) of the column has a temperature of -277°F and the reflux ratio was set to 1.52 after much trial and error. The duty of the condenser was -6.5 MW. The Reboiler (bottom stage) had a temperature of -265°F and a boilup ratio of 0.535. There were 17,500 lbmol/hr and 512,000 lb/hr going through the distillation column. There were 25 stages for this column with a tray spacing of 1 foot and a diameter 1 of 10.9 feet and a diameter 2 of 6.49 feet. The different diameters were due to the different feeds to the column. The feeds came from the heat exchanger stream 203 which was fed on stage 21 and stream 204 which was fed on stage 26. The high oxygen purity product (Stream 205) was a product that came from tray 25 and the high nitrogen purity product (Stream 210) that came from tray 1. The pressure of the column was 110.3 psig on stage 1 with a pressure drop of 0.12 psi per tray.

Oxygen Valve

Unit ID: O_2 valve
Type: Valve
Material: Stainless Steel
Specification Sheet: Page 68
Costing Data: Page 77

Temperature: -306 °F
Pressure: 5.3 psig
Vapor Fraction: 0.23

Oxygen valve was designed with ASPEN. The outlet pressure of the oxygen valve was 5.3 psig with a pressure drop of 108 psi. The outlet temperature was -306°F with a vapor fraction of 0.23. There were 4960 lbmol/hr and 149,000 lb/hr going through the oxygen valve.

Nitrogen Valve

Unit ID: N_2 valve
Type: Valve
Material: Stainless Steel
Specification Sheet: Page 68
Costing Data: Page 77

Temperature: -299 °F
Pressure: 5.3 psig
Vapor Fraction: 1

Nitrogen valve was designed with ASPEN. The outlet pressure of the oxygen valve was 5.3 psig with a pressure drop of 105 psi. The outlet temperature was -299°F with a vapor fraction of 1. There were 7610 lbmol/hr and 213,000 lb/hr going through the nitrogen valve.

Recycle Valve

Unit ID: Recycle valve
Type: Valve
Material: Stainless Steel
Specification Sheet: Page 68
Costing Data: Page 77

Temperature: -306 °F
Pressure: 5.3 psig
Vapor Fraction: .23

Recycle valve was designed with ASPEN. The outlet pressure of the oxygen valve was 5.3 psig with a pressure drop of 108 psi. The outlet temperature was -306°F with a vapor fraction of 0.23. There were 4960 lbmol/hr and 149,000 lb/hr going through the recycle valve.

Section 10
Specification Sheets

10.1 36% Case:

Main Air Compressor	Date: April 17, 2018		
Identification:	Item	Compressor	
	Item No.	MAC	
	No. Required	1	
Function:	Increases pressure and lowers volume of inlet stream		
Operation:	Continuous		
Streams:		101	102
Inlet/Outlet:		In	Out
Temperature (°F)		85	90
Pressure (psia)		14.7	98
Vapor Fraction		1	1
Mass Flow (lb/hr)		302,000	302,000
Component Mass Flow (lb/hr)			
Nitrogen		232,000	232,000
Oxygen		70,400	70,400
Component Molar Composition			
Nitrogen		0.79	0.79
Oxygen		0.21	0.21
Molar Flow (lbmol/hr)		10,500	10,500
Operating Volume Flow (cuft/hr)		4,160,000	631,000
Design Data:			
Outlet Pressure (psia)		98	
Total Work (MW)		9.65	
Total Cooling Duty (MW)		-9.59	
Net Work Required (MW)		9.65	
Net Cooling Duty (MW)		-9.59	
Utilities:	Requires 9.65 MW of power		
Comments and drawings:			

Brazed Aluminum Heat Exchanger	Date: April 17, 2018					
Identification:	Item	Heat Exchanger				
	Item No.					
	No. Required	1				
Function:	Heats and cools streams accordingly					
Operation:	Continuous					
Streams:	102	103	107	109	108	110
Inlet/Outlet:	In	Out	In	Out	In	Out
Temperature (°F)	90	-273	-278	87.5	-301	89
Pressure (psia)	98	93	19	14	19	14
Vapor Fraction	1	1	1	1	1	1
Mass Flow (lb/hr)	302,000	302,000	179,000	179,000	124,000	124,000
Component Mass Flow (lb/hr)						
Nitrogen	232,000	232,000	108,000	108,000	123,000	123,000
Oxygen	70,400	70,400	70,200	70,200	206	206
Component Molar Composition						
Nitrogen	0.79	0.79	0.64	1	0.999	0.999
Oxygen	0.21	0.21	0.36	0	0.001	0.001
Molar Flow (lbmol/hr)	10,500	10,500	6,050	6,050	4,400	4,400
Operating Volume Flow (cuft/hr)	631,000	196,000	605,000	2,540,000	381,000	1,850,000
Design Data:						
Duty (MW)	8.1					
Utilities:	Requires 8.1 MW of power					
Comments and drawings:	Brazed Aluminum, Plate-fin					

Coldbox			
Identification:	Item	Coldbox	Date: April 17, 2018
	No. Required	1	
Function:	Keep at Cryogenic temperatures.		
Operation:	Continuous		
Streams:	N/A		
Temperature (°F)	N/A		
Pressure (psia)	N/A		
Vapor Fraction	N/A		
Mass Flow (lb/hr)	N/A		
Component Mass Flow (lb/hr)	N/A		
Nitrogen	N/A		
Oxygen	N/A		
Carbon Dioxide	N/A		
Water	N/A		
Methane	N/A		
Molar Flow (lbmol/hr)	N/A		
Operating Volume Flow (cuft/hr)	N/A		
Design Data: Diameter: Excess 4 feet Height: Excess 10 feet to make space for heat exchanger			
Utilities:	N/A		
Comments and drawings:	surrounds heat exchanger to keep at cryogenic temperatures		

Column	Date: April 17, 2018			
Identification:	Item		Column	
	Item No.			
	No. Required		1	
Function:	Separates inlet air stream into enriched streams			
Operation:	Continuous			
Streams:		103	104	106
Inlet/Outlet:		In	Out	Out
Temperature (°F)		-273	-278	-285
Pressure (psia)		93	93	91
Vapor Fraction		1	0	1
Mass Flow (lb/hr)		302,000	179,000	124,000
Component Mass Flow (lb/hr)				
Nitrogen		232,000	108,000	123,000
Oxygen		70,400	70,200	206
Component Molar Composition				
Nitrogen		0.79	0.36	0.999
Oxygen		0.21	0.64	0.001
Molar Flow (lbmol/hr)		4750	2750	2000
Operating Volume Flow (cuft/hr)		196,000	3,580	77,200
Design Data:		Condenser	Reboiler	
Temperature (°F)		-285	-278	
Heat Duty (MW)		-4.16	0	
Boilup Ratio			1.77	
Reflux Ratio		1.59		
Utilities:	Produces 4.16 MW of power			
Comments and drawings:				

Heater	Date: April 17, 2018		
Identification:	Item	Heater	
	Item No.		
	No. Required		1
Function:	Increases temperature of oxygen stream before heat exchanger		
Operation:	Continuous		
Streams:		105	107
Inlet/Outlet:		In	Out
Temperature (°F)		-310	-278
Pressure (psia)		19	19
Vapor Fraction		0.19	1
Mass Flow (lb/hr)		179,000	179,000
Component Mass Flow (lb/hr)			
Nitrogen		108,000	108,000
Oxygen		70,200	70,200
Component Molar Composition			
Nitrogen		0.64	0.64
Oxygen		0.36	0.36
Molar Flow (lbmol/hr)		6,050	6,050
Operating Volume Flow (cuft/hr)		95,100	605,000
Design Data:			
Outlet Temperature (°F)		-278	
Outlet Pressure (psia)		19	
Vapor Fraction		1	
Heat Duty (MW)		4.16	
Utilities:	Requires 4.16 MW of power		
Comments and drawings:			

Valve	Date: April 17, 2018				
Identification:	Item	Valve			
	Item No.				
	No. Required		2		
Function:	Lowers pressure of and partially vaporizes inlet stream				
Operation:	Continuous				
Streams:		104	105	106	108
Inlet/Outlet:		In	Out	In	Out
Temperature (°F)		-278	-310	-285	-301
Pressure (psia)		93	19	91	19
Vapor Fraction		0	0.19	1	1
Mass Flow (lb/hr)		179,000	179,000	124,000	124,000
Component Mass Flow (lb/hr)					
Nitrogen		108,000	108,000	123,000	123,000
Oxygen		70,200	70,200	206	206
Component Molar Composition					
Nitrogen		0.64	0.64	0.999	1
Oxygen		0.36	0.36	0.001	0
Molar Flow (lbmol/hr)		6,050	6,050	4,400	4,400
Operating Volume Flow (cuft/hr)		3,580	95,100	77,200	381,000
Design Data:		Valve 1	Valve 2		
Pressure Drop (psia)		74	72		
Outlet Temperature (°F)		-310	-301		
Outlet Pressure (psia)		19	19		
Outlet Vapor Fraction		0.19	1		
Utilities:					
Comments and drawings:					

10.2 53% Case

Main Air Compressor	Date: April 17, 2018				
Identification:	Item	Compressor			
	Item No.	MAC			
	No. Required	2			
Function:	Increases pressure and lowers volume of inlet stream				
Operation:	Continuous				
Streams:		201	202	212	213
Inlet/Outlet:		In	Out	In	Out
Temperature (°F)		85	90	88	90
Pressure (psia)		14.7	129	18	130
Vapor Fraction		1	1	1	1
Mass Flow (lb/hr)		363,000	363,000	149,000	149,000
Component Mass Flow (lb/hr)					
Nitrogen		278,000	278,000	65,600	65,600
Oxygen		84,400	84,400	83,700	83,700
Component Molar Composition					
Nitrogen		0.79	0.79	0.47	0.47
Oxygen		0.21	0.21	0.53	0.53
Molar Flow (lbmol/hr)		12,500	12,500	4,950	4,950
Operating Volume Flow (cuft/hr)		5,000,000	575,000	1,620,000	225,000
Design Data:		Feed Air	Recycle		
Outlet Pressure (psia)		129	130		
Total Work (MW)		13.4	4.79		
Total Cooling Duty (MW)		-13.4	-4.8		
Net Work Required (MW)		13.4	4.79		
Net Cooling Duty (MW)		-13.4	-4.8		
Utilities:	Require 18.2 MW of power together				
Comments and drawings:	Streams 201 and 202 for one compressor and Streams 212 and 213 for the other				

Brazed Aluminum Heat Exchanger

Date: April 17, 2018

Identification:	Item	Heat Exchanger
	Item No.	
	No. Required	1
Function:	Heats and cools streams accordingly	
Operation:	Continuous	

Streams:	202	203	209	214	211	215	213	204	216	212
Inlet/Outlet:	In	Out	In	Out	In	Out	In	Out	In	Out
Temperature (°F)	90	-269	35	85	-299	88	90	-256	-306	88
Pressure (psia)	129	127	20	18	20	18	130	128	20	18
Vapor Fraction	1	0.98	1	1	1	1	1	1	0.23	1
Mass Flow (lb/hr)	363,000	363,000	149,000	149,000	213,000	213,000	149,000	149,000	149,000	149,000
Component Mass Flow (lb/hr)										
Nitrogen	278,000	278,000	65,600	65,600	212,000	212,000	65,600	65,600	65,600	65,600
Oxygen	84,400	84,400	83,700	83,700	700	700	84,700	84,700	84,700	84,700
Component Molar Composition										
Nitrogen	0.79	0.79	0.47	0.47	0.997	0.997	0.47	0.47	0.47	0.47
Oxygen	0.21	0.21	0.53	0.53	0.003	0.003	0.53	0.53	0.53	0.53
Molar Flow (lbmol/hr)	12,500	12,500	4,950	4,950	7,590	7,590	4,950	4,950	4,950	4,950
Operating Volume Flow (cuft/hr)	575,000	164,000	1,320,000	1,610,000	630,000	2,480,000	225,000	72,000	92,800	1,620,000

Design Data:	
Duty (MW)	13.6
UA (BTU/hr-F)	3,160,000
Hot End Temperature Approach (°F)	1.95
Cold End Temperature Approach (°F)	36.6
Hot NTU	24.4
Cold NTU	26.8

Utilities:	Requires 13.6 MW of power
Comments and drawings:	Brazed Aluminum, Plate-fin

Coldbox

Identification:	Item	Coldbox	Date: April 17, 2018
	No. Required	1	
Function:	Keep at Cryogenic temperatures.		
Operation:	Continuous		
Streams:	N/A		
Temperature (°F)	N/A		
Pressure (psia)	N/A		
Vapor Fraction	N/A		
Mass Flow (lb/hr)	N/A		
Component Mass Flow (lb/hr)	N/A		
Nitrogen	N/A		
Oxygen	N/A		
Carbon Dioxide	N/A		
Water	N/A		
Methane	N/A		
Molar Flow (lbmol/hr)	N/A		
Operating Volume Flow (cuft/hr)	N/A		
Design Data: Diameter: Excess 4 feet Height: Excess 10 feet to make space for heat exchanger			
Utilities:	N/A		
Comments and drawings:	surrounds heat exchanger to keep at cryogenic temperatures		

Column	April 17, 2018				
Identification:	Item	Column			
	Item No.				
	No. Required	1			
Function:	Separates air stream into enriched streams				
Operation:	Continuous				
Streams:		203	204	205	210
Inlet/Outlet:		In	In	Out	Out
Temperature (°F)		-269	-256	-265	-277
Pressure (psia)		127	128	128	125
Vapor Fraction		0.98	1	0	1
Mass Flow (lb/hr)		363,000	149,000	299,000	213,000
Component Mass Flow (lb/hr)					
Nitrogen		278,000	65,600	131,000	212,000
Oxygen		84,400	83,700	167,000	700
Component Molar Composition					
Nitrogen		0.79	0.47	0.47	0.997
Oxygen		0.21	0.53	0.53	0.003
Molar Flow (lbmol/hr)		12,500	4,950	9,900	7,590
Operating Volume Flow (cuft/hr)		164,000	72,000	5,870	96,900
Design Data:		Condenser	Reboiler		
Heat Duty (MW)		-6.5	0		
Outlet Temperature (°F)		-277	-265		
Outlet Pressure (psia)		125	128		
Boilup Ratio			0.53		
Reflux Ratio		1.52			
Utilities:	Produces 6.5 MW of power				
Comments and drawings:					

Heater	Date: April 17, 2018		
Identification:	Item		Heater
	Item No.		
	No. Required		1
Function:	Raises temperature of oxygen stream before entering heat exchanger.		
Operation:	Continuous		
Streams:		208	209
Inlet/Outlet:		In	Out
Temperature (°F)		-306	34.7
Pressure (psia)		20	20
Vapor Fraction		0.23	1
Mass Flow (lb/hr)		149,000	149,000
Component Mass Flow (lb/hr)			
Nitrogen		65,600	65,600
Oxygen		83,700	83,700
Component Molar Composition			
Nitrogen		0.47	0.47
Oxygen		0.53	0.53
Molar Flow (lbmol/hr)		4,950	4,950
Operating Volume Flow (cuft/hr)		92,800	1.32E+06
Design Data:			
Heat Duty (MW)		6.5	
Outlet Temperature (°F)		34.7	
Outlet Pressure (psia)		20	
Utilities:	Requires 6.5 MW of power		
Comments and drawings:			

Valve	Date: April 17, 2018						
Identification:	Item	Valve					
	Item No.						
	No. Required	3					
Function:	Lowers pressure of and partially vaporizes inlet stream						
Operation:	Continuous						
Streams:		207	208	210	211	206	209
Inlet/Outlet:		In	Out	In	Out	In	Out
Temperature (°F)		-265	-306	-277	-299	-265	-306
Pressure (psia)		128	20	125	20	128	20
Vapor Fraction		0	0.23	1	1	0	0.23
Mass Flow (lb/hr)		149,000	149,000	213,000	213,000	149,000	149,000
Component Mass Flow (lb/hr)							
Nitrogen		65,600	65,600	212,000	212,000	65,600	65,600
Oxygen		83,700	83,700	700	700	83,700	83,700
Component Molar Composition							
Nitrogen		0.47	0.47	0.997	0.997	0.47	0.47
Oxygen		0.53	0.53	0.003	0.003	0.53	0.53
Molar Flow (lbmol/hr)		4,950	4,950	7,590	7,590	4,950	4,950
Operating Volume Flow (cuft/hr)		2,940	92,800	96,900	630,000	2,940	92,800
Design Data:		Valve 1	Valve 2	Valve 3			
Pressure Drop (psia)		108	105	108			
Outlet Temperature (°F)		-306	-299	-306			
Outlet Pressure (psia)		20	20	20			
Outlet Vapor Fraction		0.23	1	0.23			
Utilities:							
Comments and drawings:	Stream 210 and 211 one valve, Streams 206 and 209 one valve, and Streams 207 and 208 one valve						

10.3 95% Case:

Main Air Compressor

Identification:	Item	Compressor	Date: April 17,2018
	Item No.	MAC	
	No. Required	1	
Function:	Compress inlet stream of air		
Operation:	Continuous		
Streams:	301	302	
Inlet/Outlet:	In	Out	
Temperature (°F)	85	95	
Pressure (psig)	0	87.3	
Vapor Fraction	1	1	
Mass Flow (lb/hr)	382,000	382,000	
Component Mass Flow (lb/hr)			
Nitrogen	293,000	293,000	
Oxygen	88,900	88,900	
Component Molar Compositon			
Nitrogen	0.79	0.79	
Oxygen	0.21	0.21	
Molar Flow (lbmol/hr)	13,200	13,200	
Operating Volume Flow (cuft/hr)	5.26E+06	770,000	
Design Data:	Outlet Pressure: 87.3 psia Total Work: 13.96 MW Total Cooling Duty: -13.76 MW Carbon Steel		
Utilities:	13.96 MWh of Electricity		
Comments and drawings:	Intercoolers between stages allows cooling in between the stages, saving work.		

Brazed Aluminum Plate-Fin Heat Exchanger

Date: April 17, 2018

Identification:	Item	Heat Exchanger							
	Item No.								
	No. Required	1							
Function:	Cool stream from compressor to cryogenic temperatures and warm the product streams.								
Operation:	Continuous								
Streams:	302	303	305	308	309	310	311	312	313
Inlet/Outlet	In	Out	Out	In	In	In	Out	Out	Out
Temperature (°F)	95	-150	-277	-289	-308	-313	80	80	80
Pressure (psia)	87.3	87.3	87.3	12.6	9	8.3	8.3	9	8.3
Vapor Fraction	1	1	0.59	0	1	1	1	1	1
Mass Flow (lb/hr)	382,000	76,300	305,000	222,000	128,000	179,000	74,700	128,000	179,000
Component Mass Flow (lb/hr)									
Nitrogen	293,000	17,800	71,100	3,505	112,000	177,000	3505	112,000	177,000
Oxygen	88,900	58,500	234,000	71,200	15,900	1780	71,200	15,900	1780
Component Molar Composition									
Nitrogen	0.79	0.79	0.79	0.053	0.889	0.991	0.053	0.889	0.991
Oxygen	0.21	0.21	0.21	0.947	0.111	0.009	0.947	0.111	0.009
Molar Flow (lbmol/hr)	13,200	2,650	10,600	2350	4500	6380	2350	4500	6380
Operating Volume Flow (cuft/hr)	770,000	83,300	104,000	1100	291,000	413,000	591,000	1.10E+06	1.6E+06

Design Data:
Duty: -12.5 MW

Utilities:

Comments and drawings: Brazed Aluminum, Plate-Fin

Coldbox

Identification:	Item	Coldbox	Date: April 17, 2018
	No. Required	1	
Function:	Keep at Cryogenic temperatures.		
Operation:	Continuous		
Streams:	N/A		
Temperature (°F)	N/A		
Pressure (psia)	N/A		
Vapor Fraction	N/A		
Mass Flow (lb/hr)	N/A		
Component Mass Flow (lb/hr)	N/A		
Nitrogen	N/A		
Oxygen	N/A		
Carbon Dioxide	N/A		
Water	N/A		
Methane	N/A		
Molar Flow (lbmol/hr)	N/A		
Operating Volume Flow (cuft/hr)	N/A		
Design Data: Diameter: Excess 4 feet Height: Excess 10 feet to make space for heat exchanger			
Utilities:	N/A		
Comments and drawings:	surrounds heat exchanger to keep at cryogenic temperatures		

Turbine		Date: April 17, 2018
Identification:	Item	Turbine
	No. Required	1
Function:	Reduce Temperature and Pressure of Stream 303.	
Operation:	Continuous	
Streams:	303	304
Inlet/Outlet:	In	Out
Temperature (°F)	-150	-244
Pressure (psia)	87.3	10.3
Vapor Fraction	1	1
Mass Flow (lb/hr)	76,300	76,300
Component Mass Flow (lb/hr)		
Nitrogen	17,800	17,800
Oxygen	58,500	58,500
Molar Composition		
Nitrogen	0.79	0.79
Oxygen	0.21	0.21
Molar Flow (lbmol/hr)	2,650	2650
Operating Volume Flow (cuft/hr)	83,300	239,000
Design Data:	Net work required: -0.48 MW Efficiency: 0.9 Outlet pressure: 10.3 psig Outlet temperature: -244 (°F) Isentropic outlet temperature: -254 (°F)	
Utilities:	Produces 0.48 MW of electricity	
Comments and drawings:		

Low Pressure Column

Date: April 17, 2018

Identification: Item: Dist Column
Item No.
No. Required: 1

Function:

Operation: Continuous

Streams:	304	306	307	308	309	310
Inlet/Outlet:	In	In	In	Out	Out	Out
Temperature (°F)	-244	-285	-279	-289	-308	-313
Pressure (psia)	10.3	77.3	78.6	12.6	9	8.3
Vapor Fraction	1	0	0	0	1	1
Mass Flow (lb/hr)	76,300	83,000	222,000	222,000	128,000	179,000
Component Mass Flow (lb/hr)						
Nitrogen	17,800	82,200	152,000	3,505	112,000	177,000
Oxygen	58,500	671	70,440	71,200	15,900	1780
Component Molar Composition						
Nitrogen	0.79	0.993	0.71	0.053	0.889	0.991
Oxygen	0.21	0.007	0.29	0.947	0.111	0.009
Molar Flow (lbmol/hr)	2650	2960	7630	2350	4500	6380
Operating Volume Flow (cuft/hr)	239,000	1880	4530	1100	291,000	413,000

Design Data:
Heat Duty: 4.1MW
Reflux Ratio: 0.38
Stages:38
Feed Stream 304 on Tray 18
Feed Stream 307 on Tray 12
Feed Stream 306 on Tray 1
Pressure Stage 1: 8.3 psig
Pressure Drop per Stage: .12
Tray Spacing: 1 foot
Diameter: 11.4 feet
Carbon Steel

Utilities: 4.1 MW electricity

Comments and drawings:

High Pressure Column

Identification:	Item	Dist Column	
	Item No.		
	No.		
	Required	1	
Function:			
Operation:	Continuous		
Streams:	305	306	307
Inlet/Outlet:	In	Out	Out
Temperature (°F)	-277	-285	-279
Pressure (psia)	87.3	77.3	78.6
Vapor Fraction	0.59	0	0
Mass Flow (lb/hr)	305,000	83,000	222,000
Component Mass Flow (lb/hr)			
Nitrogen	234,000	82,200	152,000
	71,100		
Oxygen	\	671	70,440
Component Molar Composition			
Nitrogen	0.79	0.993	0.71
Oxygen	0.21	0.007	0.29
Molar Flow (lbmol/hr)	10,600	2960	7630
Operating Volume Flow (cuft/hr)	104,000	1880	4530

Design Data:
Heat Duty: -3.97
Reflux Ratio: 1.25
Feed Stream 305 on Tray 14
Trays: 14
Pressure Stage 1: 77.3 psig
Pressure Drop per Stage: .1 psig
Tray Spacing: .75 feet
Diameter: 9.87 feet
Carbon Steel

Utilities: Generates 3.97 MW

Comments and drawings:

Section 11
Equipment Cost Summary

All equipment costs, except for the BAHXs, were estimated using correlations from Product and Process Design Principles: Synthesis, Analysis, and Design by Seider et al. The CE index was projected to be 595 in December 2018 - a 4% increase from December 2017. The cost of the BAHXs was estimated using correlations provided by our project author, Adam Brostow, and additional data from a previous senior design project that used a brazed aluminum heat exchanger (Rodrigues). To estimate the cost of the "black box" natural gas power generation plant, US Environmental Protection Agency data regarding the cost of a natural gas small scale combined heat and power system, which revealed the total installed cost to be about $650/kw of capacity (Darrow). The largest share of the equipment costs was made up by the compressors and the power plant since it was calculated as one line item. The following three tables show the equipment costs for each of our three oxygen enrichment scenarios.

Table 11.1. Equipment costs and bare module factors for 95% purity oxygen plant and power plant

Equipment Description	Purchase Cost	Bare Module Factor	Bare Module Cost
Name		(default 3.21 if blank)	
Expander	$120,000	3.21	$385,200
MAC	$4,880,000	2.15	$10,492,000
Cold Box	$240,000	4.16	$998,400
High Pressure Column	$275,000	4.16	$1,144,000
Low Pressure Column	$447,000	4.16	$1,860,000
BAHX	$750,000	3	$2,250,000
Power plant	$27,300,000	1	$27,300,000
Total			**$44,430,000**

Table 11.2. Equipment costs and bare module factors for 53% purity oxygen plant and power plant

Equipment Description	Purchase Cost	Bare Module Factor	Bare Module Cost
Name		(default 3.21 if blank)	
MAC	$4,750,000	2.15	$10,200,000
Recycle Compressor	$2,500,000	2.15	$5,400,000
Cryogenic Column	$450,000	4.16	$1,880,000
Cold box	$170,000	4.16	$710,000
BAHX	$810,000	3	$2,430,000
Power Plant	$27,300,000	1	$27,300,000
Total			**$47,920,000**

Table 11.3. Equipment costs and bare module factors for 36% purity oxygen plant and power plant

Equipment Description	Purchase Cost	Bare Module Factor	Bare Module Cost
Name		(default 3.21 if blank)	
MAC	$3,870,000	2.15	$8,320,000
Cryogenic Column	$200,000	4.16	$832,000
Cold Box	$113,000	4.16	$470,000
BAHX	$475,000	3	$1,425,000
Power Plant	$26,000,000	1	$26,000,000
Total			**$37,000,000**

Section 12
Fixed-Capital Investment Summary

The fixed capital investment summary includes the equipment expenditures shown in section 11 of this report, land expenses, site preparation and contingencies, contractor fees, and plant start-up. The following tables show the factors used to calculate the fixed-capital investment. The assumptions were discussed with industrial consultants and advisors for the project, further, they were consistent with the assumptions given in Seider et al.

Table 12.1. Assumptions and methods used to calculate the total permanent investment

Total Permanent Investment			
	% of Total Permanent Investment		
Year: **2019**	100%		(default is first year of Construction, otherwise over-ride this year)
2020	0%		
2021	0%		
2022	0%		
Cost of Site Preparations:		5.00%	of Total Bare Module Costs
Cost of Service Facilities:		5.00%	of Total Bare Module Costs
Allocated Costs for utility plants and related facilities:		$0	
Cost of Contingencies and Contractor Fees:		18.00%	of Direct Permanent Investment
Cost of Land:		2.00%	of Total Depreciable Capital
Cost of Royalties:		$0	
Cost of Plant Start-Up:		10.00%	of Total Depreciable Capital

The total permanent investments for each oxygen purity were calculated following the same rules. It is likely that this project would be undertaken by a regulated utility or a competitive electricity generator so a discount rate of 9% was used. This is a reasonable assumption according to the European Union's PRIME model (Capros). The following tables show the total permanent investments for the three oxygen purity levels including the cost of the power generation. The capital cost would be incurred in 2018 for each scenario.

Table 12.2. Total permanent investment cost for 95% oxygen and power generation.

Investment Summary				
Total Bare Module Costs:				
Fabricated Equipment	$	6,250,859		
Process Machinery	$	38,176,166		
Total Bare Module Costs:			**$**	**44,427,025**
Direct Permanent Investment				
Cost of Site Preparations:	$	2,221,351		
Cost of Service Facilities:	$	2,221,351		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			**$**	**48,869,727**
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	8,796,551		
Total Depreciable Capital			**$**	**57,666,278**
Total Permanent Investment				
Cost of Land:	$	1,153,326		
Cost of Royalties:	$	-		
Cost of Plant Start-Up:	$	5,766,628		
Total Permanent Investment - Unadjusted			$	64,586,232
Site Factor				1.00
Total Permanent Investment			**$**	**64,586,232**

Table 12.3. Total permanent investment cost for 53% oxygen and power generation.

Investment Summary				
Total Bare Module Costs:				
Fabricated Equipment	$	5,020,000		
Process Machinery	$	42,912,500		
Total Bare Module Costs:			**$**	**47,932,500**
Direct Permanent Investment				
Cost of Site Preparations:	$	2,396,625		
Cost of Service Facilities:	$	2,396,625		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			**$**	**52,725,750**
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	9,490,635		
Total Depreciable Capital			**$**	**62,216,385**
Total Permanent Investment				
Cost of Land:	$	1,244,328		
Cost of Royalties:	$	-		
Cost of Plant Start-Up:	$	6,221,639		
Total Permanent Investment - Unadjusted			$	69,682,351
Site Factor				1.00
Total Permanent Investment			**$**	**69,682,351**

Table 12.4. Total permanent investment cost for 36% oxygen and power generation.

Investment Summary				
Total Bare Module Costs:				
Fabricated Equipment	$	2,727,080		
Process Machinery	$	34,320,500		
Total Bare Module Costs:			**$**	**37,047,580**
Direct Permanent Investment				
Cost of Site Preparations:	$	1,852,379		
Cost of Service Facilities:	$	1,852,379		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			**$**	**40,752,338**
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	7,335,421		
Total Depreciable Capital			**$**	**48,087,759**
Total Permanent Investment				
Cost of Land:	$	961,755		
Cost of Royalties:	$	-		
Cost of Plant Start-Up:	$	4,808,776		
Total Permanent Investment - Unadjusted			$	53,858,290
Site Factor				1.00
Total Permanent Investment			**$**	**53,858,290**

Section 13
Operating and Variable Costs

In this section, the operating and variable costs will be tabulated. This includes the maintenance, operations, wages, utilities, raw materials, etc. First, the variable costs will be shown. These have been modeled treating the plant like a nitrogen plant, since nitrogen is the largest revenue generator, and calculating the relative production rate of electricity and relative consumption of natural gas. For each scenario, a power purchase agreement (PPA) was imagined where \$35/MWh of electricity is received, which is competitive in the electricity generation sector. Natural gas was priced at \$3.10/MCF which is a typical price an electricity generator would pay in Texas ("Natural Gas Prices"). The remaining variable costs relevant here were calculated according to the rules in table 13.1.

Table 13.1. Rules for calculating general variable expenses

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

Given the rules in table 13.1, and the known operating parameters of the plant (330 days per year and 100% of designed capacity) the variable costs could be accounted. The total output of nitrogen was known from ASPEN simulations for each scenario, then the power output and amount of natural gas required could be calculated using the oxygen flow rate. Using that information the ratios of electricity produced and natural gas required per pound of nitrogen could be formulated. Tables 13.2 through 13.4 show these results for each oxygen purity. For the 95% oxygen, and 53% oxygen case, the variable costs of power production (shown as raw materials) were larger than the revenue generated (shown as byproducts).

Table 13.2. Variable cost summary for 95% oxygen plant including power generation.

Variable Costs at 100% Capacity:			
General Expenses			
Selling / Transfer Expenses:		$	424,977
Direct Research:		$	679,963
Allocated Research:		$	70,829
Administrative Expense:		$	283,318
Management Incentive Compensation:		$	177,074
Total General Expenses		$	1,636,161
Raw Materials	$0.005785 per lb of nitrogen		$8,194,404
Byproducts	$0.005576 per lb of nitrogen		($7,899,242)
Utilities	$0.000128 per lb of nitrogen		$181,202
Total Variable Costs		**$**	**2,112,524**

Table 13.3. Variable cost summary for 53% oxygen plant including power generation.

Variable Costs at 100% Capacity:			
General Expenses			
Selling / Transfer Expenses:		$	506,397
Direct Research:		$	810,236
Allocated Research:		$	84,400
Administrative Expense:		$	337,598
Management Incentive Compensation:		$	210,999
Total General Expenses		$	1,949,629
Raw Materials	$0.004945 per lb of nitrogen		$8,346,271
Byproducts	$0.004926 per lb of nitrogen		($8,314,992)
Utilities	$0.000141 per lb of nitrogen		$238,318
Total Variable Costs		**$**	**2,219,227**

Table 13.4. Variable cost summary for 36% oxygen plant including power generation.

Variable Costs at 100% Capacity:			
General Expenses			
Selling / Transfer Expenses:		$	293,400
Direct Research:		$	469,441
Allocated Research:		$	48,900
Administrative Expense:		$	195,600
Management Incentive Compensation:		$	122,250
Total General Expenses		$	1,129,592
Raw Materials	$0.008122 per lb of nitrogen		$7,943,328
Byproducts	$0.008470 per lb of nitrogen		($8,283,672)
Utilities	$0.000127 per lb of nitrogen		$124,454
Total Variable Costs		**$**	**913,701**

For the day to day operations of the plant, one engineer was assumed to be splitting their time between the air separation and power production for $200,000/yr including benefits with the help of one control assistant for $500,000/yr including benefits. A single operator per shift was accounted for at $40/hr along with a few percent of the direct wages and benefits going towards supplies etc. The other fixed costs associated with operating the plant at 100% capacity were calculated according to the rules shown in table 13.5, which were discussed and verified with our consultants and Seider et al.

Table 13.5. Rules for calculating costs of operating the plant.

Maintenance		
Wages and Benefits:	4.50%	of Total Depreciable Capital
Salaries and Benefits:	25.00%	of Maintenance Wages and Benefits
Materials and Services:	100.00%	of Maintenance Wages and Benefits
Maintenance Overhead:	5.00%	of Maintenance Wages and Benefits
Operating Overhead		
General Plant Overhead:	7.10%	of Maintenance and Operations Wages and Benefits
Mechanical Department Services:	2.40%	of Maintenance and Operations Wages and Benefits
Employee Relations Department	5.90%	of Maintenance and Operations Wages and Benefits
Business Services	7.40%	of Maintenance and Operations Wages and Benefits
Property Taxes and Insurance		
Property Taxes and Insurance:	2.00%	of Total Depreciable Capital
Straight Line Depreciation		
Direct Plant:	8.00%	of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities
Allocated Plant:	6.00%	of 1.18 times the Allocated Costs for Utility Plants and Related Facilities
Other Annual Expenses		
Rental Fees (Office and Laboratory Space):	$0	
Licensing Fees:	$0	
Miscellaneous:	$0	
Depletion Allowance		
Annual Depletion Allowance:	$0	

The metrics in table 13.5 combined with the labor costs as described above were used to calculate the fixed operating costs of the plant at 100% capacity.

Table 13.6. Total fixed costs for operating the plant at 100% of it's capacity.

Purity (%)	Total Fixed Costs
95	$8,683,842
54	$9,304,136
36	$4,270,379

Section 14
Important Considerations

14.1 Plant Location

Several factors are critical to give the highest chance of success. The key factors are a nearby nitrogen customer, cheap and easily accessible natural gas, a reliable electricity market and ideally oil and gas drilling customer interested in CO_2. The vast natural gas pipeline network and industrial processes involving nitrogen in the gulf coast made the area best suited for this plant. The plant would partner with a nearby firm and build a nitrogen pipe that can feed a steady flow of nitrogen. Additionally, the industrial area would be able to make quick use of the 30 MW of electricity. There are certainly other areas of the US with similar characteristics, but the drilling industry in the gulf coast set it apart. While modeling and analysis of carbon capture were outside the scope of our project, in reality it would be necessary for an oxy fuel plant to take advantage of the increased concentration of CO_2 in it's flue gas.

14.2 Environmental Issues

There are well documented environmental issues associated with burning fossil fuels. Carbon dioxide emissions, NOx and SOx, and other pollutants are a concern especially in the gulf coast where many counties are non attainment zones for one or more pollutants. The emissions control systems involved in the power plant are outside the scope of this project. Since carbon capture was not included in our design, this plant would actually emit more CO_2 per MWh sold than a traditional natural gas plant because of the extra power required to run the ASU. However, this plant lays the groundwork for a potential part of the climate change solution.This could be mitigated by switching the design to combined cycle or doing the additional work to capture the CO_2 from the flue gas. The oxy fuel increases the proportion of the flue gas that is CO_2 so it would be easier to capture than in a traditional natural gas power plant.

The plant would also show reduced NO_x emissions since a large portion of the nitrogen that would otherwise enter the boiler is separated out before combustion. oxy fuel boilers often produce high concentrations of NO_x due to increased flame temperature, but the total flow rate would be lower (Bensakhria). Natural gas, in general, has very low sulfur, particulate, and heavy metal concentrations, so those pollutants pose little environmental risk for this project. Natural gas has high combustion efficiency so little carbon monoxide or volatile organic compounds (VOCs) are produced ("Natural Gas Combustion"). However, drilling is not without environmental consequences. Air emissions and water usage at the drilling site are a significant environmental concern for experts in this field (Raimi).

14.3 Safety

The operation of an oxy fuel power plant has unique safety considerations. The most concerning of which is boiler explosions. The temperature of the boiler will need to be regulated very carefully by recycling the flue gas. An additional emergency air intake should be included on the boiler in case the flue gas recycle fails. The natural gas should not be in contact with extremely high purity oxygen at any point which mitigates much of the risk.

Air separation plants also have four main hazards: rapid oxidation, embrittlement, pressure excursions due to vaporizing liquids, and oxygen enriched or deficient atmospheres (Schmidt). We recommend following the procedure provided by Air Products in their white paper written by Schmidt et. al. cited directly above. The plant should undergo a formal Design

Hazard Review (DHR) and a Quantitative Risk Assessment (QRA). After the completion of the DHR and QRA there should be an Operation Readiness Inspection (ORI) to ensure that the problems identified in the DHR and QRA were addressed.

Many of the risks have been addressed by assumption of dry air that is composed of oxygen and nitrogen, which was given in the problem statement. Other impurities in the air can solidify at the cryogenic temperatures, but that is not a concern for this project. Regular cleaning and maintenance of the main air compressor is necessary and a requiring workers to keep a safe distance is also good practice. Columns should be equipped with emergency pressure relief valves, and the materials of construction must be able to withstand cryogenic temperatures and should never be cold shocked to avoid damage.

14.4 Plant Startup

Plant start up should be done gradually and carefully using either liquid nitrogen or just with air. Air can be used along with the Joule-Thompson cooling to slowly bring the plant to steady state cryogenic temperatures. Alternatively, liquid nitrogen can be used to achieve these temperatures at the fastest rate possible. Prior to operation of the main air compressor, all equipment should be cleaned and thoroughly dried to avoid any frozen solids in the system.

Section 15
Profitability Analysis

The analysis of each plant design showed a negative net present value (NPV) in 2018. The 95% and 53% actually showed negative net earnings during the third production year, which is the first year at 100% production capacity. The 36% oxygen purity scenario is the closest to having a positive NPV and actually does have a slightly positive IRR. In these calculations, the nitrogen product was sold for $0.01/lb, which is reasonable, especially because the plant requires a customer who will agree to buy it whenever it is produced. The price was sacrificed for a guaranteed buyer that is located nearby. However, the profitability was very sensitive to the price of nitrogen. The profitability measures shown in the following tables are for, what we considered, the most realistic case, which is where the price of nitrogen is $0.01/lb.

Table 15.1. Profitability measures for the 95% oxygen scenario including power generation.

The Internal Rate of Return (IRR) for this project is	-4.19%
The Net Present Value (NPV) of this project in 2018 is	$(36,741,500)
ROI Analysis (Third Production Year)	
Annual Sales	**14,165,896**
Annual Costs	**(10,796,366)**
Depreciation	**(5,166,899)**
Income Tax	**431,369**
Net Earnings	**(1,366,001)**
Total Capital Investment	**65,990,923**
ROI	**-2.07%**

Table 15.2. Profitability measures for the 53% oxygen scenario including power generation.

The Internal Rate of Return (IRR) for this project is		-0.37%
The Net Present Value (NPV) of this project in 2018 is		$(30,850,600)
ROI Analysis (Third Production Year)		
Annual Sales	**16,879,909**	
Annual Costs	**(11,523,363)**	
Depreciation	**(5,574,588)**	
Income Tax	**52,330**	
Net Earnings	**(165,712)**	
Total Capital Investment	**71,379,188**	
ROI	**-0.23%**	

Table 15.3. Profitability measures for the 36% oxygen scenario including power generation.

The Internal Rate of Return (IRR) for this project is		1.18%
The Net Present Value (NPV) of this project in 2018 is		$(19,730,800)
ROI Analysis (Third Production Year)		
Annual Sales	**9,780,014**	
Annual Costs	**(5,184,080)**	
Depreciation	**(4,308,663)**	
Income Tax	**(68,945)**	
Net Earnings	**218,326**	
Total Capital Investment	**54,510,944**	
ROI	**0.40%**	

The profitability measures changed greatly with increases in the price of nitrogen. In two of the ASPEN simulations, >99.5% nitrogen was produced, therefore doing sensitivity analysis up to $0.02/lb was reasonable. At prices greater than $0.015/lb, all three cases have a positive IRR, and only the 95% case had a small negative NPV. At $0.02/lb the three scenarios were profitable with IRR's greater than 15% and NPV's greater than $24,000,000. Figure 15.1 shows these results at the three nitrogen prices discussed above for each oxygen purity. Similar results could be achieved by doubling the price of electricity. However, negotiating a PPA for any price greater than $35-$40/MWh would not be competitive with other generation sources, so it is not worthwhile to investigate these prices. Another potential consideration would be participate in the wholesale electricity markets and collect the locational marginal price (LMP) for the electricity. The biggest issue with this strategy would be facing the swings in the market. It would be beneficial during peak loads when the LMP is very high, sometimes well over $100/MWh, but there are many hours throughout the day when the LMP is below $25/MWh, or, worse yet, below $0/MWh if variable sources are over producing during a time of low demand. Given the price volatility, a stable PPA seems like the most sensible choice for a pilot scale plant.

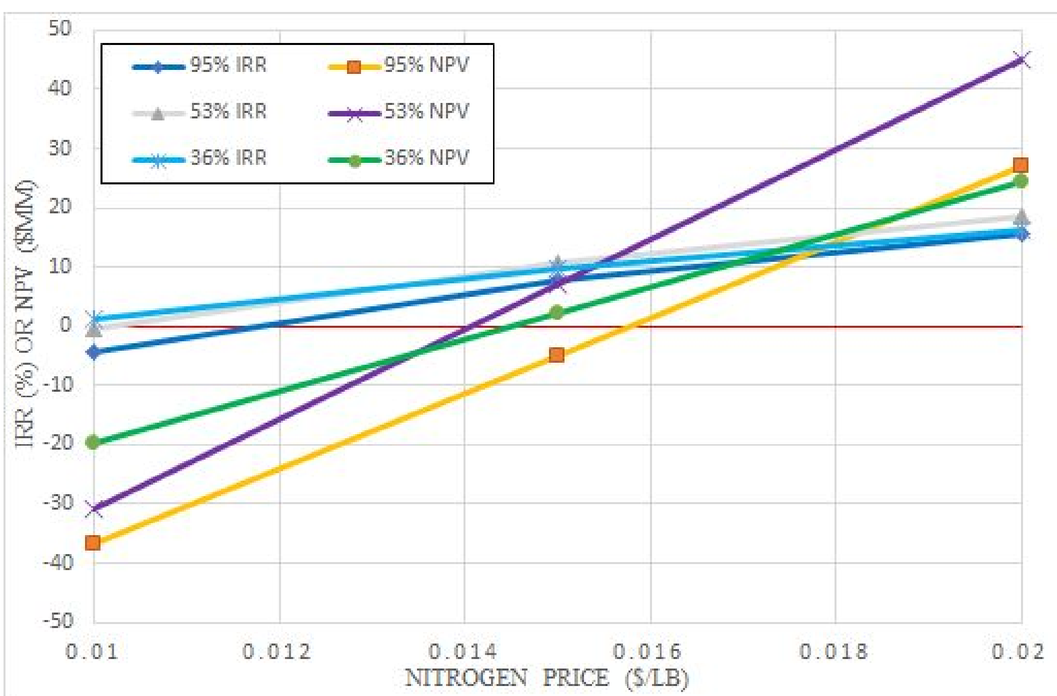


Figure 15.1. Profitability metrics' sensitivity to nitrogen price for each oxygen purity.

The real issue with the proposition of oxy fuel is that the air separation plant was far more profitable without the addition of the power plant. To model the 95% oxygen purity case, the oxygen was sold for $0.02/lb, electricity was purchased at $0.05/kWh (reasonable for the gulf coast according to EIA data), and the capital cost of the power plant was set to zero. In the 36% and 53% cases, the oxygen enriched stream was vented to the atmosphere and assigned zero value, electricity to run the compressor was purchased at $0.05/kWh, and the capital cost of the power plant was neglected. All three cases were profitable while selling the nitrogen for $0.01/lb. This analysis did neglect the cost of storage tanks for oxygen in the 95% case, but it is notable that the easiest way to make the plant profitable was to get rid of the power generation. The improved profitability metrics for each case of oxygen purity are shown in table 15.4. Each value was calculated using $0.01/lb for nitrogen, which was not profitable for any of the cases when power generation was included.

Table 15.4. IRR and NPV for the ASU's if power generation is not done.

Case	IRR	NPV
95%	36.00%	$ 54,338,000
54%	10.12%	$ 2,056,700
36%	10.31%	$ 1,270,500

The next question is what would make the oxy fuel power generation a worthwhile investment. A logical test is carbon pricing for the 95% purity model. Given the extremely high purity oxygen, there would be almost no nitrogen in the flue gas. Assuming near complete combustion of natural gas, the flue gas will consist of ⅓ CO_2 and ⅔ H_2O by mole. This means that carbon capture could be as simple as cooling the flue gas below 100 ℃ to condense the water - note this would not lend itself to sequestration since the purified CO_2 stream would be gaseous. Given the simplicity of generating a high purity CO_2 stream, the costs of doing carbon capture would be low relative to the rest of the process. Therefore, it is reasonable to do an order of magnitude estimation of the profitability assuming no changes in plant costs, and adding in a CO_2 product. By stoichiometry and known production rates from ASPEN simulations, the ratio of carbon captured to nitrogen produced on a mass basis was calculated. Then, using a reasonable $40/ton price on carbon, the profitability of the 95% oxygen purity case was calculated. The IRR and NPV were 11.24 and $8,500,000 respectively. Despite the inefficiencies of our 95% model, this case was still profitable. These numbers are certainly handwavy - considering no additional capital or power was modeled and a new product was produced. However, rigorous modeling of carbon capture was outside the scope of this project, and it is nonetheless interesting to note that simplified estimates showed carbon capture to be profitable.

Section 16
Conclusion and Recommendations

The most reasonable pricing for our products and materials yielded results that were not profitable for each oxygen purity that was tested. However, the profitability was extremely sensitive to the price of nitrogen and each case was profitable if the price of nitrogen doubled, which is not extremely likely. Doubling the price of electricity also yielded profitable results, but that is even less likely than the nitrogen price doubling. The plants were all much more profitable if the power generation was not included and the oxygen was vented for lower purities or sold for high purity. The choice of oxygen purity had little bearing on the profitability in our analysis, but could greatly affect the cost of carbon capture.

This process utilized a steam cycle and boiler to generate electricity, which seems wasteful. Most natural gas generation built today uses a combined cycle, which could increase the efficiency from about 35% to 60%, thus nearly doubling the fuel efficiency of our plant. Getting more electricity per unit of fuel would significantly increase the chances of being profitable.

Future work should rigorously model a natural gas combined cycle plant with a >95% oxygen purity stream. The back-of-the-envelope calculations described in Section 15 showed that this could be profitable with a carbon price of $40/ton. Increasing the efficiency of the ASU and rigorously modeling all of the benefits of 95% oxy fuel in a combined cycle plant with carbon capture, rather than investigating different oxygen concentrations, could be very interesting. We believe the key benefits of oxy fuel were not examined in our project due to the structure. Therefore, rigorous modeling of the oxy fuel combustion and carbon capture at a single oxygen concentration would yield more interesting and informative results. Separately, modeling the power plant as a peaker, or a plant that only operates for a few hours a day during times with sufficiently high LMP's, and sells oxygen during the other times of the day would be a very interesting future project.

Section 17
Acknowledgements

We would like to thank our project author Adam Brostow for the challenge and faculty advisor Professor Wen K. Shieh for his support. We would also like to thank them for making our capstone senior design experience rewarding and enriching.

Additionally, special thanks are due to Professor Leonard Fabiano for his help with our process simulation and valuable industry specific knowledge. We also want to show our appreciation for Professor Bruce Vrana for so readily, and pleasantly, offering countless pieces of advice and analysis that were invaluable to our project.

Lastly, it was a pleasure meeting and working with the industrial consultants. They were extremely gracious guides throughout the process. We would especially like to thank Dr. Shaibal Roy, Dr. Richard Bockrath, Mr. Stephen Tieri, Ms. Mariella P Juhasz, and Dr. P.C. Gopalratnam for their assistance on this project.

Section 18
Bibliography

18.1 Citations

Bensakhria, Ammar, and Mikel Leturia. "Natural Gas Oxy-Combustion with Flue Gas Recycling for CO2 Capture." Chemical Engineering Transactions, vol. 21, Aug. 2010, pp. 637–642., www.aidic.it/cet/10/21/107.pdf.

"Brazed Aluminum Heat Exchangers." *Fives*, cryogenics-energy.fivesgroup.com/equipment/brazed-heat-exchangers/bahx.html.

Brostow, Adam, and Donn Herron. Medium-Pressure Nitrogen Production with High Oxygen Recovery. 2 Jan. 2003.

"Buy Liquid Nitrogen or Purchase Compressed Nitrogen Gas (N2)." Praxair - Making Our Planet More Productive, www.praxair.com/gases/buy-liquid-nitrogen-or-compressed-nitrogen-gas?tab=industries.

Capros, P., et al. "Energy, Transport and GHG Emissions Trends To 2050." EU Reference Scenario 2016, 15 July 2016, ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf.

"Chemical Composition of Natural Gas." Union Gas, www.uniongas.com/about-us/about-natural-gas/chemical-composition-of-natural-gas.

"CO2 Carbon Dioxide Properties, Uses, Applications - Recovery from Industrial Sources - Concentration in Air." Universal Industrial Gases, Inc., www.uigi.com/carbondioxide.html.

Darrow, Ken, et al. "Catalog of CHP Technologies." EPA, www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies_section_4._technology_characterization_-_steam_turbines.pdf

Hanania, Jordan, et al. "Natural Gas Power Plant." Energy Education, energyeducation.ca/encyclopedia/Natural_gas_power_plant.

"How Do Air Bags Work?" Scientific American, www.scientificamerican.com/article/how-do-air-bags-work/.

Kiriishi, Ken, et al. High Efficiency Furnace with Oxy-Fuel Combustion and Zero-Emission by CO2 Recovery. members.igu.org/html/wgc2009/papers/docs/wgcFinal00580.pdf.

"Map of Oil & Natural Gas Drilling Health & Safety Issues Cell Towers vs Oil & Gas Drilling Find Safe Campgrounds ." Map of Oil & Gas Health & Safety Issues, www.drillingmaps.com/.

"Natural Gas Combustion." AP 42: Compilation of Air Emissions Factors, 5th ed., vol. 1, United States Environmental Protection Agency, 1998.

"Natural Gas Prices." Natural Gas Electric Power Price, U.S. Energy Information Administration, 30 Mar. 2018, www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PEU_DMcf_m.htm.

Nitrogen Generation for the Aerospace Industry. Parker Hannifin, www.parker.com/literature/domnick hunter Industrial Division/Literature .

Raimi, Daniel. The Fracking Debate: the Risks, Benefits, and Uncertainties of the Shale Revolution. Columbia University Press, 2018.

Rodrigues, Luisa Hermann, et al. Low Grade Heat Recovery. www.mountainelm.com/LGHFinal.pdf.

Schmidt, William P., et al. "Safe Design and Operation of a Cryogenic Air Separation Unit."Process Safety Progress, vol. 20, no. 4, 2001, pp. 269–279., doi:10.1002/prs.680200409.

Thorogood, Robert M, et al. Cryogenic Process for Nitrogen Production with Oxygen-Enriched Recycle. 19 Sept. 1989.

Section 19
Appendices

Appendix A: Sample Calculations

Cooling water requirements:
Cooling water requirements for compressor intercoolers.

Inlet: 85℉
Outlet: 110℉
c = specific heat of water = 1 BTU/(lb ℉)
Q (ASPEN) = 32,740,000 BTU/hr

$$Q = mc\Delta T$$
$$\Delta T = 110℉ - 85℉ = 25℉$$
$$m = \frac{Q}{c\Delta T} = \frac{32{,}740{,}000\ BTU/hr}{1(BTU/lb℉)\times 25(℉)} = 1,300,000\ lb/hr\ of\ cooling\ water$$

Natural gas feed requirements:
For this example, the amount of gas required to generate 30 MW of electricity using a steam turbine will be calculated.

Lower heating value of natural gas: 0.0149 MWh/kg
Rankine cycle thermal efficiency: 35%
$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$

$$m = \frac{30MWh}{0.0149(MWh/kg)\times 0.35} = 5753\ kg \text{ natural gas to produce 30 MWh}$$
$$\frac{5753\ kg}{1\ hr} = 5753\ kg/hr \text{ natural gas, which will produce 30 MW}$$

Net Power calculation:
Given an oxygen flow rate, calculating net power.

O_2 flow rate (ASPEN) = 1000 kmol/hr
Molecular weight of natural gas = 16 kg/kmol

$$\frac{1kmol\ gas}{2\ kmol\ oxygen} \times 1000\ kmol\ oxygen = 500\ kmol/hr\ of\ natural\ gas$$
$$500\ kmol \times \frac{16kg}{kmol} = 8000\ kg/hr\ of\ natural\ gas$$

From above,

$$Power = 8000(kg/hr) \times 0.0149(MWh/kg) \times .35 = 41.7\ MW$$

Compressor work (ASPEN) = 12 MW

$$Net\ power = 41.7\ MW - 12\ MW = 29.7\ MW$$

Appendix B: EPA New Source Requirements

The following information was obtained from the EPA's New Source Performance Standards (NSPS) for electric utility steam generating units. These rules apply to units with a potential electrical output of 25 MW or greater. The full text of the regulation (40 CFR part 60 subpart Da) can be found at the following web address: https://www.gpo.gov/fdsys/pkg/CFR-2015-title40-vol7/pdf/CFR-2015-title40-vol7-part60-subpartDa.pdf

Table A.1. NOx emission standards for new sources per unit heat input.

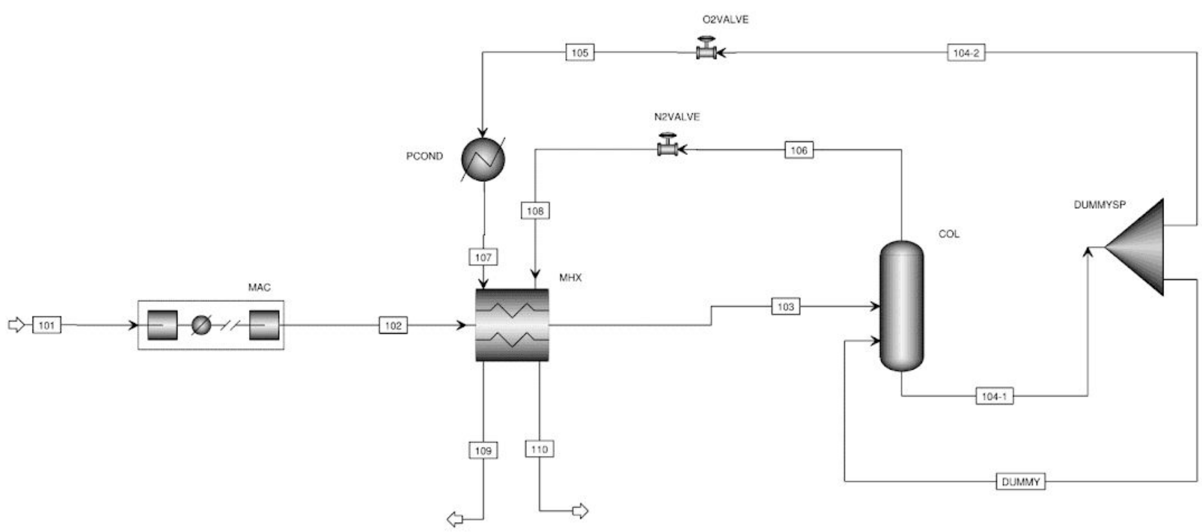
Fuel type	Emission limit for heat input	
	ng/J	lb/MMBtu
Gaseous fuels:		
Coal-derived fuels	210	0.50
All other fuels	86	0.20
Liquid fuels:		
Coal-derived fuels	210	0.50
Shale oil	210	0.50
All other fuels	130	0.30
Solid fuels:		
Coal-derived fuels	210	0.50
Any fuel containing more than 25%, by weight, coal refuse	(1)	(1)
Any fuel containing more than 25%, by weight, lignite if the lignite is mined in North Dakota, South Dakota, or Montana, and is combusted in a slag tap furnace[2]	340	0.80
Any fuel containing more than 25%, by weight, lignite not subject to the 340 ng/J heat input emission limit[2]	260	0.60
Subbituminous coal	210	0.50
Bituminous coal	260	0.60
Anthracite coal	260	0.60
All other fuels	260	0.60

[1] Exempt from NO_X standards and NO_X monitoring requirements.
[2] Any fuel containing less than 25%, by weight, lignite is not prorated but its percentage is added to the percentage of the predominant fuel.

Appendix C: ASPEN Block and Stream reports

36% Oxygen

Flowsheet



Block Report

```
 BLOCK:  MHX       MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 102               103

   COLD SIDE:    INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 108               110
                 107               109

   PROPERTIES FOR STREAM 102
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

   PROPERTIES FOR STREAM 107
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

   PROPERTIES FOR STREAM 108
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                       ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           20943.9          20943.9          0.00000
```

```
    MASS(LB/HR   )           604240.        604240.        0.00000
    ENTHALPY(BTU/HR  )      -0.260736E+08  -0.260736E+08   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  ***


SPECIFICATIONS FOR STREAM 102     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              F                      -273.000
PRESSURE DROP                      PSI                       5.00000
MAXIMUM NO. ITERATIONS                                      30
CONVERGENCE TOLERANCE                                        0.000100000

SPECIFICATIONS FOR STREAM 107     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              F                        87.5000
PRESSURE DROP                      PSI                       5.00000
MAXIMUM NO. ITERATIONS                                      30
CONVERGENCE TOLERANCE                                        0.000100000

SPECIFICATIONS FOR STREAM 108     :
TWO    PHASE      FLASH
PRESSURE DROP                      PSI                       5.00000
MAXIMUM NO. ITERATIONS                                      30
CONVERGENCE TOLERANCE                                        0.000100000

                      ***  RESULTS  ***

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

102      -0.27621E+08   -273.00      93.000       1.0000
107       0.15564E+08     87.50      14.000       1.0000
108       0.12057E+08     88.58      14.000       1.0000


          ------------------------------------------
          |                                        |
102       |                                        | 103
--------->|          10472.     LBMOL/HR           |--------->
   90.00  |                                        |  -273.00
          |                                        |
109       |                                        | 107
<---------|          6062.7     LBMOL/HR           |<---------
   87.50  |                                        |  -278.26
          |                                        |
110       |                                        | 108
<---------|          4409.2     LBMOL/HR           |<---------
   88.58  |                                        |  -300.79
          |                                        |
          ------------------------------------------
```

```
BLOCK:  MHX      MODEL: MHEATX
------------------------------

  HOT SIDE:    INLET STREAM     OUTLET STREAM
               ------------     -------------
               102              103

  COLD SIDE:   INLET STREAM     OUTLET STREAM
               ------------     -------------
               108              110
               107              109

  PROPERTIES FOR STREAM 102
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

  PROPERTIES FOR STREAM 107
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

  PROPERTIES FOR STREAM 108
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT         RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           20943.9         20943.9         0.00000
      MASS(LB/HR   )           604240.         604240.         0.00000
      ENTHALPY(BTU/HR  )     -0.260736E+08   -0.260736E+08     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  ***


  SPECIFICATIONS FOR STREAM 102     :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                F                         -273.000
  PRESSURE DROP                        PSI                          5.00000
  MAXIMUM NO. ITERATIONS                                           30
  CONVERGENCE TOLERANCE                                             0.000100000

  SPECIFICATIONS FOR STREAM 107     :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                F                           87.5000
  PRESSURE DROP                        PSI                          5.00000
  MAXIMUM NO. ITERATIONS                                           30
  CONVERGENCE TOLERANCE                                             0.000100000

  SPECIFICATIONS FOR STREAM 108     :
  TWO    PHASE      FLASH
  PRESSURE DROP                        PSI                          5.00000
  MAXIMUM NO. ITERATIONS                                           30
```

CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

INLET STREAM	DUTY BTU/HR	OUTLET TEMPERATURE F	OUTLET PRESSURE PSIA	OUTLET VAPOR FRAC
102	-0.27621E+08	-273.00	93.000	1.0000
107	0.15564E+08	87.50	14.000	1.0000
108	0.12057E+08	88.58	14.000	1.0000

```
          ------------------------------------------
          |                                        |
 102      |                                        | 103
--------->|          10472.     LBMOL/HR           |--------->
   90.00  |                                        |  -273.00
          |                                        |
 109      |                                        | 107
<---------|          6062.7     LBMOL/HR           |<---------
   87.50  |                                        |  -278.26
          |                                        |
 110      |                                        | 108
<---------|          4409.2     LBMOL/HR           |<---------
   88.58  |                                        |  -300.79
          |                                        |
          ------------------------------------------
```

BLOCK: MHX MODEL: MHEATX

	INLET STREAM	OUTLET STREAM
HOT SIDE:	102	103
COLD SIDE:	108	110
	107	109

PROPERTIES FOR STREAM 102
PROPERTY OPTION SET: PSRK RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 107
PROPERTY OPTION SET: PSRK RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 108
PROPERTY OPTION SET: PSRK RKS-MHV1 EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

TOTAL BALANCE	IN	OUT	RELATIVE DIFF.
MOLE(LBMOL/HR)	20943.9	20943.9	0.00000
MASS(LB/HR)	604240.	604240.	0.00000
ENTHALPY(BTU/HR)	-0.260736E+08	-0.260736E+08	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  ***


  SPECIFICATIONS FOR STREAM 102     :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                F                       -273.000
  PRESSURE DROP                        PSI                        5.00000
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000

  SPECIFICATIONS FOR STREAM 107     :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                F                         87.5000
  PRESSURE DROP                        PSI                        5.00000
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000

  SPECIFICATIONS FOR STREAM 108     :
  TWO    PHASE      FLASH
  PRESSURE DROP                        PSI                        5.00000
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000

                             ***  RESULTS  ***

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

 102       -0.27621E+08   -273.00      93.000        1.0000
 107        0.15564E+08     87.50      14.000        1.0000
 108        0.12057E+08     88.58      14.000        1.0000


          ------------------------------------------
          |                                        |
 102      |                                        | 103
--------->|          10472.     LBMOL/HR           |--------->
    90.00 |                                        |  -273.00
          |                                        |
 109      |                                        | 107
<---------|          6062.7     LBMOL/HR           |<---------
    87.50 |                                        |  -278.26
          |                                        |
 110      |                                        | 108
<---------|          4409.2     LBMOL/HR           |<---------
    88.58 |                                        |  -300.79
          |                                        |
          ------------------------------------------
```

```
BLOCK:  COL      MODEL: RADFRAC
-------------------------------
   INLETS   - 103      STAGE  15
              DUMMY    STAGE   1
   OUTLETS  - 106      STAGE   1
              104-1    STAGE  15
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           10472.0        10472.0         0.00000
      MASS(LB/HR   )           302120.        302120.        0.192664E-15
      ENTHALPY(BTU/HR  )      -0.268473E+08   -0.410453E+08    0.345910

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

  ****   INPUT PARAMETERS   ****

   NUMBER OF STAGES                                      15
   ALGORITHM OPTION                                    STANDARD
   ABSORBER OPTION                                     NO
   INITIALIZATION OPTION                               STANDARD
   HYDRAULIC PARAMETER CALCULATIONS                    NO
   INSIDE LOOP CONVERGENCE METHOD                      BROYDEN
   DESIGN SPECIFICATION METHOD                         NESTED
   MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                25
   MAXIMUM NO. OF INSIDE LOOP ITERATIONS                 10
   MAXIMUM NUMBER OF FLASH ITERATIONS                    30
   FLASH TOLERANCE                                        0.000100000
   OUTSIDE LOOP CONVERGENCE TOLERANCE                     0.000100000

  ****   COL-SPECS   ****

   MOLAR VAPOR DIST / TOTAL DIST                          1.00000
   MOLAR DISTILLATE RATE          LBMOL/HR            4,409.25
   REBOILER DUTY                  BTU/HR                  0.0

  ****    PROFILES   ****

   P-SPEC          STAGE   1  PRES, PSIA                 91.0000

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


  ***   COMPONENT SPLIT FRACTIONS   ***
```

OUTLET STREAMS

	106	104-1
COMPONENT:		
OXYGEN	.29239E-02	.99708
NITROGEN	.53220	.46780

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	-285.026
BOTTOM STAGE TEMPERATURE	F	-277.764
TOP STAGE LIQUID FLOW	LBMOL/HR	6,988.72
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	6,062.71
TOP STAGE VAPOR FLOW	LBMOL/HR	4,409.25
BOILUP VAPOR FLOW	LBMOL/HR	10,706.5
MOLAR REFLUX RATIO		1.58501
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-0.141980+08
REBOILER DUTY	BTU/HR	0.0

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

DEW POINT	0.62477E-11	STAGE= 12
BUBBLE POINT	0.19593E-11	STAGE= 14
COMPONENT MASS BALANCE	0.20530E-10	STAGE= 10 COMP=OXYGEN
ENERGY BALANCE	0.30102E-12	STAGE= 15

**** PROFILES ****

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

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	-285.03	91.000	-4687.1	-2656.2	-.14198+08
2	-284.95	91.120	-4687.8	-2655.8	
3	-284.85	91.240	-4689.0	-2655.2	
14	-278.81	92.560	-4818.7	-2609.9	
15	-277.76	92.680	-4838.4	-2602.0	

STAGE	FLOW RATE LBMOL/HR		FEED RATE LBMOL/HR			PRODUCT RATE LBMOL/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	6989.	4409.					4409.2452
2	6983.	0.1140E+05					
3	6974.	0.1139E+05					
14	6297.	0.1081E+05					
15	6063.	0.1071E+05			.10472+05	6062.7122	

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR		FEED RATE LB/HR			PRODUCT RATE LB/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	0.1959E+06	0.1235E+06					.12354+06

```
  2 0.1958E+06 0.3194E+06
  3 0.1957E+06 0.3193E+06
 14 0.1843E+06 0.3095E+06
 15 0.1786E+06 0.3078E+06                     .30212+06  .17858+06

                       ****   MOLE-X-PROFILE     ****
  STAGE     OXYGEN        NITROGEN
     1     0.33759E-02   0.99662
     2     0.60907E-02   0.99391
     3     0.99228E-02   0.99008
    14     0.31423       0.68577
    15     0.36167       0.63833

                       ****   MOLE-Y-PROFILE     ****
  STAGE     OXYGEN        NITROGEN
     1     0.14583E-02   0.99854
     2     0.26341E-02   0.99737
     3     0.42978E-02   0.99570
    14     0.15635       0.84365
    15     0.18542       0.81458

                       ****   K-VALUES           ****
  STAGE     OXYGEN        NITROGEN
     1     0.43197        1.0019
     2     0.43248        1.0035
     3     0.43312        1.0057
    14     0.49757        1.2302
    15     0.51268        1.2761

                       ****   MASS-X-PROFILE     ****
  STAGE     OXYGEN        NITROGEN
     1     0.38543E-02   0.99615
     2     0.69512E-02   0.99305
     3     0.11318E-01   0.98868
    14     0.34357       0.65643
    15     0.39290       0.60710

                       ****   MASS-Y-PROFILE     ****
  STAGE     OXYGEN        NITROGEN
     1     0.16654E-02   0.99833
     2     0.30077E-02   0.99699
     3     0.49062E-02   0.99509
    14     0.17471       0.82529
    15     0.20636       0.79364




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


      *** DEFINITIONS ***

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

```
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE
```

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	-285.03	-284.95
2	-284.95	-284.85
3	-284.85	-284.73
14	-278.81	-277.76
15	-277.76	-273.06

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	0.19587E+06	0.31942E+06	4532.8	0.19948E+06	28.027	28.024
2	0.19579E+06	0.31933E+06	4526.6	0.19922E+06	28.038	28.031
3	0.19565E+06	0.31920E+06	4517.1	0.19896E+06	28.053	28.040
14	0.18429E+06	0.30784E+06	3765.9	0.19417E+06	29.266	28.752
15	0.17858E+06	0.30212E+06	3582.1	0.19709E+06	29.455	28.850

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	43.212	1.6013	0.75176E-01	0.66472E-02	4.7018
2	43.253	1.6029	0.75235E-01	0.66522E-02	4.7117
3	43.314	1.6043	0.75333E-01	0.66585E-02	4.7270
14	48.937	1.5854	0.86063E-01	0.70358E-02	6.0990
15	49.852	1.5329	0.87829E-01	0.72277E-02	6.2943

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.11805	39131.	0.25242E+06
2	0.98736E-02	0.11803	39082.	0.25223E+06
3	0.15380E-01	0.11797	39021.	0.25201E+06
14	0.21838	0.10776	35529.	0.24448E+06
15	0.19538	0.10365	35105.	0.24402E+06

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

*******************
*** SECTION   1 ***
*******************
```

```
STARTING STAGE NUMBER                                              2
ENDING STAGE NUMBER                                               15
FLOODING CALCULATION METHOD                                 GLITSCH6

DESIGN PARAMETERS
-----------------
PEAK CAPACITY FACTOR                                         1.00000
SYSTEM FOAMING FACTOR                                        1.00000
FLOODING FACTOR                                              0.80000
MINIMUM COLUMN DIAMETER          FT                          1.00000
MINIMUM DC AREA/COLUMN AREA                                  0.100000
HOLE AREA/ACTIVE AREA                                        0.100000

TRAY SPECIFICATIONS
-------------------
TRAY TYPE                                                    SIEVE
NUMBER OF PASSES                                                   4
TRAY SPACING                     FT                          1.00000


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

STAGE WITH MAXIMUM DIAMETER                                        2
COLUMN DIAMETER                  FT                          8.74233
DC AREA/COLUMN AREA                                          0.093750
SIDE DOWNCOMER VELOCITY          FT/SEC                      0.22344
FLOW PATH LENGTH                 FT                          1.64054
SIDE DOWNCOMER WIDTH             FT                          0.53180
SIDE WEIR LENGTH                 FT                          4.17916
CENTER DOWNCOMER WIDTH           FT                          0.34340
CENTER WEIR LENGTH               FT                          8.73558
OFF-CENTER DOWNCOMER WIDTH       FT                          0.38658
OFF-CENTER SHORT WEIR LENGTH     FT                          7.55573
OFF-CENTER LONG WEIR LENGTH      FT                          7.95559
TRAY CENTER TO OCDC CENTER       FT                          2.00553


                      **** SIZING PROFILES ****
```

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA PER PANEL	SIDE DC AREA PER PANEL
	FT	SQFT	SQFT	SQFT
2	8.7423	60.027	12.005	1.4069
3	8.7423	60.027	12.005	1.4069
4	8.7423	60.027	12.005	1.4069
5	8.7423	60.027	12.005	1.4069
6	8.7423	60.027	12.005	1.4069
7	8.7423	60.027	12.005	1.4069
8	8.7423	60.027	12.005	1.4069
9	8.7423	60.027	12.005	1.4069
10	8.7423	60.027	12.005	1.4069
11	8.7423	60.027	12.005	1.4069
12	8.7423	60.027	12.005	1.4069
13	8.7423	60.027	12.005	1.4069
14	8.7423	60.027	12.005	1.4069
15	8.7423	60.027	12.005	1.4069

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
2	80.00	0.7238E-01	0.5273	48.67
3	79.87	0.7235E-01	0.5262	48.57
4	79.71	0.7232E-01	0.5247	48.43
5	79.48	0.7229E-01	0.5226	48.24
6	79.18	0.7226E-01	0.5197	47.97
7	78.78	0.7223E-01	0.5159	47.62
8	78.25	0.7220E-01	0.5108	47.15
9	77.57	0.7218E-01	0.5044	46.56
10	76.73	0.7217E-01	0.4965	45.83
11	75.72	0.7217E-01	0.4872	44.97
12	74.58	0.7220E-01	0.4771	44.04
13	73.39	0.7226E-01	0.4668	43.09
14	72.25	0.7235E-01	0.4572	42.20
15	71.11	0.7210E-01	0.4452	41.09

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.1508	0.6039	0.2279	54.61
3	0.1505	0.6040	0.2280	54.50
4	0.1501	0.6040	0.2282	54.34
5	0.1496	0.6042	0.2284	54.13
6	0.1489	0.6043	0.2286	53.84
7	0.1479	0.6045	0.2289	53.46
8	0.1465	0.6048	0.2292	52.96
9	0.1448	0.6051	0.2297	52.31
10	0.1427	0.6055	0.2302	51.52
11	0.1401	0.6060	0.2308	50.60
12	0.1372	0.6064	0.2315	49.58
13	0.1342	0.6067	0.2322	48.55
14	0.1314	0.6070	0.2329	47.58
15	0.1269	0.6073	0.2332	46.72

```
BLOCK:  DUMMYSP  MODEL: FSPLIT
------------------------------
  INLET STREAM:          104-1
  OUTLET STREAMS:        104-2       DUMMY
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT         RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)         6062.71         6062.71          0.00000
      MASS(LB/HR   )         178576.         178576.          0.00000
      ENTHALPY(BTU/HR  )   -0.293336E+08   -0.293336E+08     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=104-2    FRAC=         1.00000

                         ***  RESULTS  ***

 STREAM= 104-2          SPLIT=          1.00000     KEY=  0    STREAM-ORDER=   1
         DUMMY                          0.0               0                    2

BLOCK:  MAC      MODEL: MCOMPR
------------------------------
  INLET STREAMS:    101          TO STAGE   1
  OUTLET STREAMS:   102        FROM STAGE   3
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           10472.0         10472.0         0.00000
      MASS(LB/HR   )           302120.         302120.         0.00000
      ENTHALPY(BTU/HR  )       556542.         773629.       -0.280609

                    ***  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
  NUMBER OF STAGES                                         3
  FINAL PRESSURE, PSIA                                    98.0000
  DISTRIBUTION AMONG STAGES                               EQUAL P-RATIO

                  COMPRESSOR SPECIFICATIONS PER STAGE

  STAGE                     MECHANICAL      ISENTROPIC
  NUMBER                    EFFICIENCY      EFFICIENCY


    1                        1.000          0.7200
    2                        1.000          0.7200
    3                        1.000          0.7200

                  COOLER SPECIFICATIONS PER STAGE

  STAGE     PRESSURE DROP     TEMPERATURE
  NUMBER    PSI               F

    1       0.000             90.00
    2       0.000             90.00
    3       0.000             90.00

                         ***  RESULTS  ***

  FINAL PRESSURE, PSIA                                    98.0000
  TOTAL WORK REQUIRED, HP                             12,943.0
  TOTAL COOLING DUTY , BTU/HR                             -0.327156+08
```

```
                        ***  PROFILE  ***

                        COMPRESSOR PROFILE

  STAGE      OUTLET       PRESSURE     OUTLET
  NUMBER     PRESSURE     RATIO        TEMPERATURE
             PSIA                      F

    1        27.67        1.882        233.9
    2        52.07        1.882        240.2
    3        98.00        1.882        240.1

  STAGE      INDICATED      BRAKE
  NUMBER     HORSEPOWER     HORSEPOWER
             HP             HP
    1        4286.          4286.
    2        4327.          4327.
    3        4330.          4330.

  STAGE      HEAD           VOLUMETRIC    ISENTROPIC
  NUMBER     DEVELOPED      FLOW          EFFICIENCY
             FT-LBF/LB      CUFT/HR
    1       0.2022E+05     0.4164E+07     0.7200
    2       0.2042E+05     0.2233E+07     0.7200
    3       0.2043E+05     0.1187E+07     0.7200

                        COOLER PROFILE

  STAGE      OUTLET         OUTLET       COOLING     VAPOR
  NUMBER     TEMPERATURE    PRESSURE     LOAD        FRACTION
             F              PSIA         BTU/HR

    1         90.00          27.67       -.1056E+08   1.000
    2         90.00          52.07       -.1105E+08   1.000
    3         90.00          98.00       -.1110E+08   1.000

BLOCK:  N2VALVE  MODEL: VALVE
-----------------------------
  INLET STREAM:           106
  OUTLET STREAM:          108
  PROPERTY OPTION SET:    PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           4409.25         4409.25         0.00000
      MASS(LB/HR   )           123544.         123544.         0.00000
      ENTHALPY(BTU/HR  )      -0.117118E+08   -0.117118E+08     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                          19.0000
   VALVE FLOW COEF CALC.                                  NO

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

                        ***  RESULTS  ***

   VALVE PRESSURE DROP       PSI                           72.0000

BLOCK:  O2VALVE  MODEL: VALVE
-----------------------------
  INLET STREAM:           104-2
  OUTLET STREAM:          105
  PROPERTY OPTION SET:    PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           6062.71         6062.71         0.00000
      MASS(LB/HR   )           178576.         178576.         0.00000
      ENTHALPY(BTU/HR  )      -0.293336E+08   -0.293336E+08     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                          19.0000
   VALVE FLOW COEF CALC.                                  NO

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

                        ***  RESULTS  ***

   VALVE PRESSURE DROP       PSI                           73.6800

BLOCK:  PCOND    MODEL: HEATER
------------------------------
  INLET STREAM:           105
  OUTLET STREAM:          107
  PROPERTY OPTION SET:    PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           6062.71         6062.71         0.00000
      MASS(LB/HR   )           178576.         178576.         0.00000
      ENTHALPY(BTU/HR  )      -0.293336E+08   -0.151354E+08   -0.484023
```

```
                    ***  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  PQ  FLASH
 PRESSURE DROP                       PSI                        0.0
 SPECIFIED HEAT DUTY                 BTU/HR                     0.141981+08
 MAXIMUM NO. ITERATIONS                                        30
 CONVERGENCE TOLERANCE                                          0.000100000



                         ***  RESULTS  ***
 OUTLET TEMPERATURE    F                                   -278.26
 OUTLET PRESSURE       PSIA                                  19.000
 OUTLET VAPOR FRACTION                                        1.0000



 V-L PHASE EQUILIBRIUM :

    COMP              F(I)          X(I)          Y(I)          K(I)
    OXYGEN           0.36167       0.68986       0.36167       2.0415
    NITROGEN         0.63833       0.31014       0.63833       5.6302
```

<u>Stream Report</u>

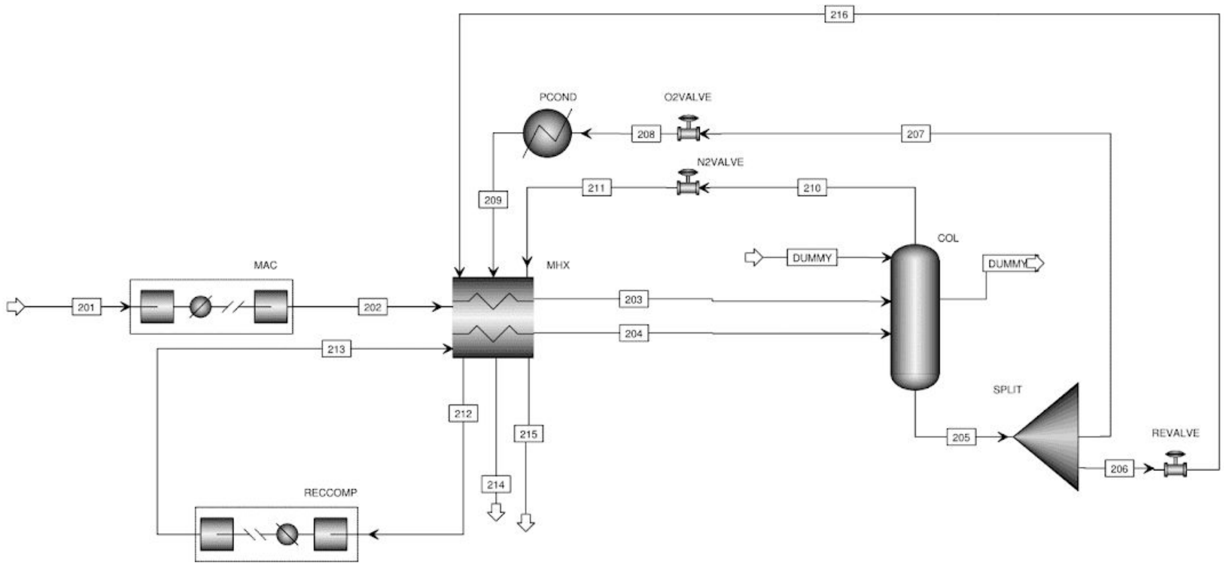
```
101 102 103 104-1 104-2
-----------------------

STREAM ID               101        102        103        104-1      104-2
FROM :                  ----       MAC        MHX        COL        DUMMYSP
TO   :                  MAC        MHX        COL        DUMMYSP    O2VALVE

SUBSTREAM: MIXED
PHASE:                  VAPOR      VAPOR      VAPOR      LIQUID     LIQUID
COMPONENTS: LBMOL/HR
  OXYGEN              2199.1111  2199.1111  2199.1111  2192.6811  2192.6811
  NITROGEN            8272.8464  8272.8464  8272.8464  3870.0312  3870.0312
TOTAL FLOW:
  LBMOL/HR            1.0472+04  1.0472+04  1.0472+04  6062.7122  6062.7122
  LB/HR               3.0212+05  3.0212+05  3.0212+05  1.7858+05  1.7858+05
  CUFT/HR             4.1644+06  6.3093+05  1.9640+05  3582.1109  3582.1109
STATE VARIABLES:
  TEMP   F              85.0000    90.0000  -273.0000  -277.7637  -277.7637
  PRES   PSIA           14.7000    98.0000    93.0000    92.6800    92.6800
  VFRAC                  1.0000     1.0000     1.0000     0.0        0.0
  LFRAC                  0.0        0.0        0.0        1.0000     1.0000
  SFRAC                  0.0        0.0        0.0        0.0        0.0
ENTHALPY:
  BTU/LBMOL             53.1459    73.8763 -2563.7371 -4838.3560 -4838.3560
  BTU/LB                 1.8421     2.5607   -88.8631  -164.2635  -164.2635
```

```
  BTU/HR               5.5654+05  7.7363+05 -2.6847+07 -2.9334+07 -2.9334+07
ENTROPY:
  BTU/LBMOL-R             1.1182    -2.6127   -10.4386   -22.4763   -22.4763
  BTU/LB-R             3.8759-02 -9.0562-02    -0.3618    -0.7631    -0.7631
DENSITY:
  LBMOL/CUFT           2.5147-03  1.6598-02  5.3321-02     1.6925     1.6925
  LB/CUFT              7.2549-02     0.4788     1.5383    49.8522    49.8522
AVG MW                   28.8504    28.8504    28.8504    29.4548    29.4548

105 106 107 108 109
-------------------

STREAM ID                105        106        107        108        109
FROM :                   O2VALVE    COL        PCOND      N2VALVE    MHX
TO   :                   PCOND      N2VALVE    MHX        MHX        ----

SUBSTREAM: MIXED
PHASE:                   MIXED      VAPOR      VAPOR      VAPOR      VAPOR
COMPONENTS: LBMOL/HR
  OXYGEN               2192.6811     6.4300  2192.6811     6.4300  2192.6811
  NITROGEN             3870.0312  4402.8152  3870.0312  4402.8152  3870.0312
TOTAL FLOW:
  LBMOL/HR             6062.7122  4409.2452  6062.7122  4409.2452  6062.7122
  LB/HR                1.7858+05  1.2354+05  1.7858+05  1.2354+05  1.7858+05
  CUFT/HR              9.5148+04  7.7238+04  6.0463+05  3.8134+05  2.5429+06
STATE VARIABLES:
  TEMP   F             -310.4517  -285.0259  -278.2571  -300.7938    87.5000
  PRES   PSIA            19.0000    91.0000    19.0000    19.0000    14.0000
  VFRAC                   0.1896     1.0000     1.0000     1.0000     1.0000
  LFRAC                   0.8104     0.0        0.0        0.0        0.0
  SFRAC                   0.0        0.0        0.0        0.0        0.0
ENTHALPY:
  BTU/LBMOL           -4838.3560 -2656.1875 -2496.4815 -2656.1875    70.6464
  BTU/LB                -164.2635   -94.7985   -84.7562   -94.7985     2.3985
  BTU/HR              -2.9334+07 -1.1712+07 -1.5135+07 -1.1712+07  4.2831+05
ENTROPY:
  BTU/LBMOL-R            -22.1234   -11.9239    -6.8406    -9.0663     1.5262
  BTU/LB-R                -0.7511    -0.4256    -0.2322    -0.3236  5.1814-02
DENSITY:
  LBMOL/CUFT           6.3719-02  5.7087-02  1.0027-02  1.1562-02  2.3842-03
  LB/CUFT                 1.8768     1.5995     0.2953     0.3240  7.0225-02
AVG MW                   29.4548    28.0193    29.4548    28.0193    29.4548

110 DUMMY
---------

STREAM ID                110        DUMMY
FROM :                   MHX        DUMMYSP
TO   :                   ----       COL

SUBSTREAM: MIXED
PHASE:                   VAPOR      MISSING
COMPONENTS: LBMOL/HR
  OXYGEN                  6.4300     0.0
  NITROGEN             4402.8152     0.0
TOTAL FLOW:
  LBMOL/HR             4409.2452     0.0
  LB/HR                1.2354+05     0.0
  CUFT/HR              1.8534+06     0.0
```

```
STATE VARIABLES:
  TEMP    F              88.5757    MISSING
  PRES    PSIA           14.0000    MISSING
  VFRAC                   1.0000    MISSING
  LFRAC                   0.0       MISSING
  SFRAC                   0.0       MISSING
ENTHALPY:
  BTU/LBMOL              78.3433    MISSING
  BTU/LB                  2.7961    MISSING
  BTU/HR              3.4544+05     MISSING
ENTROPY:
  BTU/LBMOL-R             0.2622    MISSING
  BTU/LB-R            9.3563-03     MISSING
DENSITY:
  LBMOL/CUFT          2.3790-03     MISSING
  LB/CUFT             6.6658-02     MISSING
AVG MW                   28.0193    MISSING
```

53% Oxygen

Flowsheet



Block Report

```
BLOCK:  MHX      MODEL: MHEATX
------------------------------

  HOT SIDE:    INLET STREAM     OUTLET STREAM
               ------------     -------------
               202              203
               213              204
```

```
COLD SIDE:    INLET STREAM      OUTLET STREAM
              ------------      -------------
              211               215
              209               214
              216               212

PROPERTIES FOR STREAM 202
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 209
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 213
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 211
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 216
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )           15900.0         15900.0         0.00000
    MASS(KG/HR   )           464417.         464417.         0.00000
    ENTHALPY(CAL/SEC )      -0.308761E+07   -0.308761E+07    0.245209E-06

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

                      ***  INPUT DATA  ***

MAXIMUM NO. ITERATIONS                                    30
CONVERGENCE TOLERANCE                                      0.000100000

SPECIFICATIONS FOR STREAM 202     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              K                        105.928
PRESSURE DROP                      ATM                        0.13609
MAXIMUM NO. ITERATIONS                                       30
CONVERGENCE TOLERANCE                                         0.000100000

SPECIFICATIONS FOR STREAM 209     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              K                        302.594
PRESSURE DROP                      ATM                        0.13609
MAXIMUM NO. ITERATIONS                                       30
CONVERGENCE TOLERANCE                                         0.000100000

SPECIFICATIONS FOR STREAM 213     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              K                        113.150
PRESSURE DROP                      ATM                        0.13609
MAXIMUM NO. ITERATIONS                                       30
```

```
  CONVERGENCE TOLERANCE                                               0.000100000

  SPECIFICATIONS FOR STREAM 211     :
  TWO    PHASE     FLASH
  PRESSURE DROP                       ATM                             0.13609
  MAXIMUM NO. ITERATIONS                                             30
  CONVERGENCE TOLERANCE                                               0.000100000

  SPECIFICATIONS FOR STREAM 216     :
  TWO    PHASE     FLASH
  PRESSURE DROP                       ATM                             0.13609
  MAXIMUM NO. ITERATIONS                                             30
  CONVERGENCE TOLERANCE                                               0.000100000

                        ***  RESULTS  ***

 INLET                  OUTLET       OUTLET       OUTLET
 STREAM    DUTY         TEMPERATURE  PRESSURE     VAPOR FRAC
           CAL/SEC      K            ATM

 202       -0.23689E+07    105.93      8.6418        0.9820
 209        0.12237E+06    302.59      1.2248        1.0000
 213       -0.88492E+06    113.15      8.7099        1.0000
 211        0.14488E+07    304.29      1.2248        1.0000
 216        0.16826E+07    304.29      1.2248        1.0000


          ------------------------------------------
          |                                        |
 202      |                                        | 203
--------->|        5700.0     KMOL/HR              |--------->
   305.37 |                                        |   105.93
          |                                        |
 213      |                                        | 204
--------->|        2250.0     KMOL/HR              |--------->
   305.37 |                                        |   113.15
          |                                        |
 214      |                                        | 209
<---------|        2250.0     KMOL/HR              |<---------
   302.59 |                                        |   274.66
          |                                        |
 215      |                                        | 211
<---------|        3450.0     KMOL/HR              |<---------
   304.29 |                                        |    89.07
          |                                        |
 212      |                                        | 216
<---------|        2250.0     KMOL/HR              |<---------
   304.29 |                                        |    85.57
          |                                        |
          ------------------------------------------


                        ***  INTERNAL ANALYSIS  ***

 FLOW IS COUNTERCURRENT.
 DUTY                               0.32538E+07 CAL/SEC
 UA                                 0.39831E+06 CAL/SEC-K
 AVERAGE LMTD (DUTY/UA)              8.1691     K
```

```
  MIN TEMP APPROACH                  1.0845     K
  HOT-SIDE TEMP APPROACH             1.0845     K
  COLD-SIDE TEMP APPROACH            20.354     K
  HOT-SIDE NTU                       24.415
  COLD-SIDE NTU                      26.773

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

POINT  BUBBLE POINT
  CAL/SEC          K          K          K          K     CAL/SEC-K   CAL/SEC
CAL/SEC-K

   0.000         105.93     85.57     20.35
  0.3435E+05    105.99     85.72     20.27     20.31   1691.       0.3435E+05   1691.
LOC    DP  202
  0.1317E+06    113.15     86.15     27.00     23.47   4146.       0.9731E+05   5837.
OUT 213
  0.4067E+06    128.53     87.33     41.20     33.60   8187.       0.2751E+06
0.1402E+05
  0.7343E+06    147.72     88.42     59.31     49.70   6591.       0.3276E+06
0.2062E+05        DP  216
  0.7373E+06    147.91     89.07     58.83     59.07   50.33        2973.
0.2067E+05        IN  211
  0.8135E+06    152.48     95.75     56.73     57.78   1318.       0.7616E+05
0.2198E+05
  0.1220E+07    177.21    131.89     45.33     50.82   8004.       0.4067E+06
0.2999E+05
  0.1627E+07    202.42    168.39     34.03     39.41  0.1032E+05   0.4067E+06
0.4031E+05
  0.2034E+07    227.92    205.05     22.87     28.08  0.1448E+05   0.4067E+06
0.5479E+05
  0.2440E+07    253.62    241.80     11.82     16.74  0.2429E+05   0.4067E+06
0.7909E+05
  0.2804E+07    276.70    274.66      2.04      5.57  0.6528E+05   0.3634E+06
0.1444E+06        IN  209
  0.2847E+07    279.46    277.47      1.99      2.01  0.2151E+05   0.4332E+05
0.1659E+06
  0.3235E+07    304.18    302.59      1.58      1.78  0.2182E+06   0.3880E+06
0.3841E+06        OUT 209
  0.3254E+07    305.37    304.29      1.08      1.32  0.1422E+05   0.1874E+05
0.3983E+06  GBL



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

 BLOCK:  MHX      MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 202               203
                 213               204

   COLD SIDE:    INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 211               215
                 209               214
```

```
              216              212

   PROPERTIES FOR STREAM 202
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

   PROPERTIES FOR STREAM 209
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

   PROPERTIES FOR STREAM 213
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

   PROPERTIES FOR STREAM 211
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

   PROPERTIES FOR STREAM 216
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           15900.0        15900.0         0.00000
       MASS(KG/HR   )           464417.        464417.         0.00000
       ENTHALPY(CAL/SEC )     -0.308761E+07  -0.308761E+07    0.245209E-06

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

                       ***  INPUT DATA  ***

   MAXIMUM NO. ITERATIONS                                 30
   CONVERGENCE TOLERANCE                                   0.000100000

   SPECIFICATIONS FOR STREAM 202     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE             K                      105.928
   PRESSURE DROP                     ATM                      0.13609
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   SPECIFICATIONS FOR STREAM 209     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE             K                      302.594
   PRESSURE DROP                     ATM                      0.13609
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   SPECIFICATIONS FOR STREAM 213     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE             K                      113.150
   PRESSURE DROP                     ATM                      0.13609
   MAXIMUM NO. ITERATIONS                                    30
   CONVERGENCE TOLERANCE                                      0.000100000

   SPECIFICATIONS FOR STREAM 211     :
   TWO    PHASE      FLASH
```

```
 PRESSURE DROP                          ATM                          0.13609
 MAXIMUM NO. ITERATIONS                                            30
 CONVERGENCE TOLERANCE                                               0.000100000

 SPECIFICATIONS FOR STREAM 216     :
 TWO    PHASE      FLASH
 PRESSURE DROP                          ATM                          0.13609
 MAXIMUM NO. ITERATIONS                                            30
 CONVERGENCE TOLERANCE                                               0.000100000

                        ***  RESULTS  ***

INLET                  OUTLET       OUTLET       OUTLET
STREAM    DUTY         TEMPERATURE  PRESSURE     VAPOR FRAC
          CAL/SEC      K            ATM

202       -0.23689E+07    105.93       8.6418        0.9820
209        0.12237E+06    302.59       1.2248        1.0000
213       -0.88492E+06    113.15       8.7099        1.0000
211        0.14488E+07    304.29       1.2248        1.0000
216        0.16826E+07    304.29       1.2248        1.0000


         ------------------------------------------
         |                                        |
202      |                                        | 203
--------->|        5700.0     KMOL/HR             |--------->
  305.37 |                                        |   105.93
         |                                        |
213      |                                        | 204
--------->|        2250.0     KMOL/HR             |--------->
  305.37 |                                        |   113.15
         |                                        |
214      |                                        | 209
<---------|        2250.0     KMOL/HR             |<---------
  302.59 |                                        |   274.66
         |                                        |
215      |                                        | 211
<---------|        3450.0     KMOL/HR             |<---------
  304.29 |                                        |    89.07
         |                                        |
212      |                                        | 216
<---------|        2250.0     KMOL/HR             |<---------
  304.29 |                                        |    85.57
         |                                        |
         ------------------------------------------


                        ***  INTERNAL ANALYSIS  ***

FLOW IS COUNTERCURRENT.
DUTY                               0.32538E+07 CAL/SEC
UA                                 0.39831E+06 CAL/SEC-K
AVERAGE LMTD (DUTY/UA)              8.1691     K
MIN TEMP APPROACH                   1.0845     K
HOT-SIDE TEMP APPROACH              1.0845     K
COLD-SIDE TEMP APPROACH             20.354     K
HOT-SIDE NTU                        24.415
```

```
  COLD-SIDE NTU                        26.773

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

POINT  BUBBLE POINT
  CAL/SEC          K          K          K          K     CAL/SEC-K   CAL/SEC
CAL/SEC-K


   0.000         105.93     85.57     20.35
  0.3435E+05    105.99     85.72     20.27     20.31   1691.       0.3435E+05   1691.
LOC    DP  202
  0.1317E+06    113.15     86.15     27.00     23.47   4146.       0.9731E+05   5837.
OUT 213
  0.4067E+06    128.53     87.33     41.20     33.60   8187.       0.2751E+06
0.1402E+05
  0.7343E+06    147.72     88.42     59.31     49.70   6591.       0.3276E+06
0.2062E+05      DP  216
  0.7373E+06    147.91     89.07     58.83     59.07   50.33        2973.
0.2067E+05      IN  211
  0.8135E+06    152.48     95.75     56.73     57.78   1318.       0.7616E+05
0.2198E+05
  0.1220E+07    177.21    131.89     45.33     50.82   8004.       0.4067E+06
0.2999E+05
  0.1627E+07    202.42    168.39     34.03     39.41  0.1032E+05  0.4067E+06
0.4031E+05
  0.2034E+07    227.92    205.05     22.87     28.08  0.1448E+05  0.4067E+06
0.5479E+05
  0.2440E+07    253.62    241.80     11.82     16.74  0.2429E+05  0.4067E+06
0.7909E+05
  0.2804E+07    276.70    274.66      2.04      5.57  0.6528E+05  0.3634E+06
0.1444E+06      IN  209
  0.2847E+07    279.46    277.47      1.99      2.01  0.2151E+05  0.4332E+05
0.1659E+06
  0.3235E+07    304.18    302.59      1.58      1.78  0.2182E+06  0.3880E+06
0.3841E+06      OUT 209
  0.3254E+07    305.37    304.29      1.08      1.32  0.1422E+05  0.1874E+05
0.3983E+06  GBL



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

 BLOCK:  MHX       MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 202               203
                 213               204

   COLD SIDE:    INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 211               215
                 209               214
                 216               212

   PROPERTIES FOR STREAM 202
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE
```

```
PROPERTIES FOR STREAM 209
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 213
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 211
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 216
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )           15900.0         15900.0         0.00000
    MASS(KG/HR   )           464417.         464417.         0.00000
    ENTHALPY(CAL/SEC )     -0.308761E+07   -0.308761E+07    0.245209E-06

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

                       ***  INPUT DATA  ***

MAXIMUM NO. ITERATIONS                                    30
CONVERGENCE TOLERANCE                                      0.000100000

SPECIFICATIONS FOR STREAM 202     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              K                         105.928
PRESSURE DROP                      ATM                         0.13609
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.000100000

SPECIFICATIONS FOR STREAM 209     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              K                         302.594
PRESSURE DROP                      ATM                         0.13609
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.000100000

SPECIFICATIONS FOR STREAM 213     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE              K                         113.150
PRESSURE DROP                      ATM                         0.13609
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.000100000

SPECIFICATIONS FOR STREAM 211     :
TWO    PHASE      FLASH
PRESSURE DROP                      ATM                         0.13609
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.000100000
```

```
   SPECIFICATIONS FOR STREAM 216     :
   TWO    PHASE     FLASH
   PRESSURE DROP                       ATM                        0.13609
   MAXIMUM NO. ITERATIONS                                        30
   CONVERGENCE TOLERANCE                                          0.000100000

                         ***  RESULTS  ***

  INLET                 OUTLET       OUTLET       OUTLET
  STREAM    DUTY        TEMPERATURE  PRESSURE     VAPOR FRAC
            CAL/SEC     K            ATM

  202       -0.23689E+07    105.93      8.6418        0.9820
  209        0.12237E+06    302.59      1.2248        1.0000
  213       -0.88492E+06    113.15      8.7099        1.0000
  211        0.14488E+07    304.29      1.2248        1.0000
  216        0.16826E+07    304.29      1.2248        1.0000


           ------------------------------------------
           |                                        |
  202      |                                        | 203
 --------->|         5700.0     KMOL/HR             |--------->
    305.37 |                                        |   105.93
           |                                        |
  213      |                                        | 204
 --------->|         2250.0     KMOL/HR             |--------->
    305.37 |                                        |   113.15
           |                                        |
  214      |                                        | 209
 <---------|         2250.0     KMOL/HR             |<---------
    302.59 |                                        |   274.66
           |                                        |
  215      |                                        | 211
 <---------|         3450.0     KMOL/HR             |<---------
    304.29 |                                        |    89.07
           |                                        |
  212      |                                        | 216
 <---------|         2250.0     KMOL/HR             |<---------
    304.29 |                                        |    85.57
           |                                        |
           ------------------------------------------


                         ***  INTERNAL ANALYSIS  ***

  FLOW IS COUNTERCURRENT.
  DUTY                                0.32538E+07 CAL/SEC
  UA                                  0.39831E+06 CAL/SEC-K
  AVERAGE LMTD (DUTY/UA)               8.1691     K
  MIN TEMP APPROACH                    1.0845     K
  HOT-SIDE TEMP APPROACH               1.0845     K
  COLD-SIDE TEMP APPROACH              20.354     K
  HOT-SIDE NTU                         24.415
  COLD-SIDE NTU                        26.773

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

```
POINT  BUBBLE POINT
  CAL/SEC         K          K          K          K     CAL/SEC-K   CAL/SEC
CAL/SEC-K

   0.000         105.93     85.57      20.35
  0.3435E+05    105.99     85.72      20.27      20.31   1691.       0.3435E+05   1691.
LOC    DP  202
  0.1317E+06    113.15     86.15      27.00      23.47   4146.       0.9731E+05   5837.
OUT 213
  0.4067E+06    128.53     87.33      41.20      33.60   8187.       0.2751E+06
0.1402E+05
  0.7343E+06    147.72     88.42      59.31      49.70   6591.       0.3276E+06
0.2062E+05        DP  216
  0.7373E+06    147.91     89.07      58.83      59.07   50.33        2973.
0.2067E+05        IN  211
  0.8135E+06    152.48     95.75      56.73      57.78   1318.       0.7616E+05
0.2198E+05
  0.1220E+07    177.21    131.89      45.33      50.82   8004.       0.4067E+06
0.2999E+05
  0.1627E+07    202.42    168.39      34.03      39.41  0.1032E+05   0.4067E+06
0.4031E+05
  0.2034E+07    227.92    205.05      22.87      28.08  0.1448E+05   0.4067E+06
0.5479E+05
  0.2440E+07    253.62    241.80      11.82      16.74  0.2429E+05   0.4067E+06
0.7909E+05
  0.2804E+07    276.70    274.66       2.04       5.57  0.6528E+05   0.3634E+06
0.1444E+06        IN  209
  0.2847E+07    279.46    277.47       1.99       2.01  0.2151E+05   0.4332E+05
0.1659E+06
  0.3235E+07    304.18    302.59       1.58       1.78  0.2182E+06   0.3880E+06
0.3841E+06        OUT 209
  0.3254E+07    305.37    304.29       1.08       1.32  0.1422E+05   0.1874E+05
0.3983E+06  GBL


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

 BLOCK:  MHX      MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 202              203
                 213              204

   COLD SIDE:    INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 211              215
                 209              214
                 216              212

   PROPERTIES FOR STREAM 202
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

   PROPERTIES FOR STREAM 209
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE
```

```
PROPERTIES FOR STREAM 213
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 211
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

PROPERTIES FOR STREAM 216
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )            15900.0         15900.0         0.00000
    MASS(KG/HR   )            464417.         464417.         0.00000
    ENTHALPY(CAL/SEC )      -0.308761E+07   -0.308761E+07    0.245209E-06

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

                       ***  INPUT DATA  ***

MAXIMUM NO. ITERATIONS                                     30
CONVERGENCE TOLERANCE                                       0.000100000

SPECIFICATIONS FOR STREAM 202     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               K                          105.928
PRESSURE DROP                       ATM                          0.13609
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                            0.000100000

SPECIFICATIONS FOR STREAM 209     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               K                          302.594
PRESSURE DROP                       ATM                          0.13609
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                            0.000100000

SPECIFICATIONS FOR STREAM 213     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               K                          113.150
PRESSURE DROP                       ATM                          0.13609
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                            0.000100000

SPECIFICATIONS FOR STREAM 211     :
TWO    PHASE      FLASH
PRESSURE DROP                       ATM                          0.13609
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                            0.000100000

SPECIFICATIONS FOR STREAM 216     :
TWO    PHASE      FLASH
PRESSURE DROP                       ATM                          0.13609
MAXIMUM NO. ITERATIONS                                         30
```

CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

INLET STREAM	DUTY CAL/SEC	OUTLET TEMPERATURE K	OUTLET PRESSURE ATM	OUTLET VAPOR FRAC
202	-0.23689E+07	105.93	8.6418	0.9820
209	0.12237E+06	302.59	1.2248	1.0000
213	-0.88492E+06	113.15	8.7099	1.0000
211	0.14488E+07	304.29	1.2248	1.0000
216	0.16826E+07	304.29	1.2248	1.0000

```
           -----------------------------------------
           |                                       |
 202       |                                       | 203
---------->|         5700.0     KMOL/HR            |--------->
   305.37  |                                       |   105.93
           |                                       |
 213       |                                       | 204
---------->|         2250.0     KMOL/HR            |--------->
   305.37  |                                       |   113.15
           |                                       |
 214       |                                       | 209
<----------|         2250.0     KMOL/HR            |<---------
   302.59  |                                       |   274.66
           |                                       |
 215       |                                       | 211
<----------|         3450.0     KMOL/HR            |<---------
   304.29  |                                       |    89.07
           |                                       |
 212       |                                       | 216
<----------|         2250.0     KMOL/HR            |<---------
   304.29  |                                       |    85.57
           |                                       |
           -----------------------------------------
```

*** INTERNAL ANALYSIS ***

FLOW IS COUNTERCURRENT.

DUTY	0.32538E+07	CAL/SEC
UA	0.39831E+06	CAL/SEC-K
AVERAGE LMTD (DUTY/UA)	8.1691	K
MIN TEMP APPROACH	1.0845	K
HOT-SIDE TEMP APPROACH	1.0845	K
COLD-SIDE TEMP APPROACH	20.354	K
HOT-SIDE NTU	24.415	
COLD-SIDE NTU	26.773	

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

POINT BUBBLE POINT
CAL/SEC K K K K CAL/SEC-K CAL/SEC
CAL/SEC-K

```
   0.000        105.93     85.57     20.35
  0.3435E+05    105.99     85.72     20.27     20.31   1691.      0.3435E+05   1691.
LOC     DP  202
  0.1317E+06    113.15     86.15     27.00     23.47   4146.      0.9731E+05   5837.
OUT 213
  0.4067E+06    128.53     87.33     41.20     33.60   8187.      0.2751E+06
0.1402E+05
  0.7343E+06    147.72     88.42     59.31     49.70   6591.      0.3276E+06
0.2062E+05        DP  216
  0.7373E+06    147.91     89.07     58.83     59.07   50.33       2973.
0.2067E+05        IN  211
  0.8135E+06    152.48     95.75     56.73     57.78   1318.      0.7616E+05
0.2198E+05
  0.1220E+07    177.21    131.89     45.33     50.82   8004.      0.4067E+06
0.2999E+05
  0.1627E+07    202.42    168.39     34.03     39.41  0.1032E+05  0.4067E+06
0.4031E+05
  0.2034E+07    227.92    205.05     22.87     28.08  0.1448E+05  0.4067E+06
0.5479E+05
  0.2440E+07    253.62    241.80     11.82     16.74  0.2429E+05  0.4067E+06
0.7909E+05
  0.2804E+07    276.70    274.66      2.04      5.57  0.6528E+05  0.3634E+06
0.1444E+06        IN  209
  0.2847E+07    279.46    277.47      1.99      2.01  0.2151E+05  0.4332E+05
0.1659E+06
  0.3235E+07    304.18    302.59      1.58      1.78  0.2182E+06  0.3880E+06
0.3841E+06        OUT 209
  0.3254E+07    305.37    304.29      1.08      1.32  0.1422E+05  0.1874E+05
0.3983E+06  GBL


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

 BLOCK:  COL      MODEL: RADFRAC
 -------------------------------
    INLETS   - 203      STAGE  21
               204      STAGE  25
               DUMMY    STAGE   1
    OUTLETS  - 210      STAGE   1
               205      STAGE  25
               DUMMY2   STAGE   2
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           7950.00         7950.00       -0.114402E-15
       MASS(KG/HR   )           232208.         232208.        0.406286E-11
       ENTHALPY(CAL/SEC )     -0.317073E+07   -0.472359E+07    0.328746

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

```
                    *********************
                    ****  INPUT DATA  ****
                    *********************

 ****   INPUT PARAMETERS   ****

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

 ****   COL-SPECS   ****

  MOLAR VAPOR DIST / TOTAL DIST                                 1.00000
  MOLAR DISTILLATE RATE          KMOL/HR                    3,450.00
  REBOILER DUTY                  CAL/SEC                        0.0

 ****    PROFILES   ****

  P-SPEC          STAGE   1  PRES, ATM                          8.50575

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


 ***   COMPONENT SPLIT FRACTIONS   ***

                        OUTLET STREAMS
                        --------------
              210          205          DUMMY2
  COMPONENT:
  OXYGEN      .41640E-02   .99584       0.0000
  NITROGEN    .61806       .38194       0.0000


 ***    SUMMARY OF KEY RESULTS    ***

  TOP STAGE TEMPERATURE          K                            101.556
  BOTTOM STAGE TEMPERATURE       K                            108.199
  TOP STAGE LIQUID FLOW          KMOL/HR                    5,255.67
  BOTTOM STAGE LIQUID FLOW       KMOL/HR                    4,500.00
  TOP STAGE VAPOR FLOW           KMOL/HR                    3,450.00
  BOILUP VAPOR FLOW              KMOL/HR                    2,405.75
  MOLAR REFLUX RATIO                                            1.52338
  MOLAR BOILUP RATIO                                            0.97906
  CONDENSER DUTY (W/O SUBCOOL)   CAL/SEC               -1,552,860.
  REBOILER DUTY                  CAL/SEC                        0.0
```

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

  DEW POINT                         0.56569E-08  STAGE= 15
  BUBBLE POINT                      0.43439E-08  STAGE= 25
  COMPONENT MASS BALANCE            0.93720E-08  STAGE= 10 COMP=OXYGEN
  ENERGY BALANCE                    0.56203E-09  STAGE= 25


 ****    PROFILES   ****

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

                                        ENTHALPY
STAGE TEMPERATURE   PRESSURE            CAL/MOL             HEAT DUTY
      K             ATM            LIQUID        VAPOR        CAL/SEC

  1   101.56        8.5057       -2533.8      -1470.7      -.15529+07
  2   101.61        8.5139       -2534.6      -1470.4
  3   101.68        8.5221       -2535.6      -1469.9
 19   105.50        8.6527       -2610.5      -1440.4
 20   105.72        8.6609       -2614.2      -1438.7
 21   105.77        8.6691       -2614.6      -1438.4
 22   105.87        8.6772       -2615.9      -1437.7
 24   106.71        8.6936       -2629.4      -1431.1
 25   108.20        8.7017       -2651.3      -1419.4

STAGE     FLOW RATE                  FEED RATE                PRODUCT RATE
           KMOL/HR                    KMOL/HR                   KMOL/HR
      LIQUID     VAPOR       LIQUID    VAPOR    MIXED      LIQUID    VAPOR
  1  5256.      3450.                                                3450.0000
  2  5248.      8706.
  3  5239.      8698.
 19  4676.      8156.
 20  4652.      8126.               5597.3758
 21  4752.      2505.      102.6241
 22  4743.      2502.
 24  4656.      2468.
 25  4500.      2406.               2250.0014              4500.0014

  ****  MASS FLOW PROFILES  ****

STAGE     FLOW RATE                  FEED RATE                PRODUCT RATE
           KG/HR                      KG/HR                     KG/HR
      LIQUID     VAPOR       LIQUID    VAPOR    MIXED      LIQUID    VAPOR
  1 0.1474E+06 0.9669E+05                                            .96686+05
  2 0.1472E+06 0.2440E+06
  3 0.1471E+06 0.2439E+06
 19 0.1373E+06 0.2345E+06
 20 0.1369E+06 0.2339E+06           .16142+06
 21 0.1398E+06 0.7212E+05  3026.7052
 22 0.1397E+06 0.7209E+05
 24 0.1383E+06 0.7154E+05
 25 0.1355E+06 0.7053E+05           .67761+05              .13552+06

                       ****   MOLE-X-PROFILE     ****
  STAGE     OXYGEN         NITROGEN
     1    0.60508E-02    0.99395
     2    0.10066E-01    0.98993
```

```
     3     0.15127E-01   0.98487
    19     0.33600       0.66400
    20     0.35277       0.64723
    21     0.35558       0.64442
    22     0.36210       0.63790
    24     0.42389       0.57611
    25     0.52759       0.47241

                         ****   MOLE-Y-PROFILE     ****
   STAGE     OXYGEN        NITROGEN
     1     0.28775E-02   0.99712
     2     0.47933E-02   0.99521
     3     0.72148E-02   0.99279
    19     0.18353       0.81647
    20     0.19457       0.80543
    21     0.19649       0.80351
    22     0.20089       0.79911
    24     0.24435       0.75565
    25     0.32691       0.67309

                         ****   K-VALUES           ****
   STAGE     OXYGEN        NITROGEN
     1     0.47555        1.0032
     2     0.47618        1.0053
     3     0.47695        1.0080
    19     0.54622        1.2296
    20     0.55156        1.2444
    21     0.55258        1.2469
    22     0.55480        1.2527
    24     0.57645        1.3116
    25     0.61964        1.4248

                         ****   MASS-X-PROFILE     ****
   STAGE     OXYGEN        NITROGEN
     1     0.69057E-02   0.99309
     2     0.11482E-01   0.98852
     3     0.17242E-01   0.98276
    19     0.36629       0.63371
    20     0.38370       0.61630
    21     0.38661       0.61339
    22     0.39335       0.60665
    24     0.45666       0.54334
    25     0.56057       0.43943

                         ****   MASS-Y-PROFILE     ****
   STAGE     OXYGEN        NITROGEN
     1     0.32855E-02   0.99671
     2     0.54714E-02   0.99453
     3     0.82328E-02   0.99177
    19     0.20431       0.79569
    20     0.21627       0.78373
    21     0.21834       0.78166
    22     0.22309       0.77691
    24     0.26974       0.73026
    25     0.35683       0.64317

 BLOCK:  MAC       MODEL: MCOMPR
 ------------------------------
   INLET STREAMS:     201          TO STAGE    1
```

```
OUTLET STREAMS:   202        FROM STAGE   3
PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                                IN                OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(KMOL/HR )           5700.00          5700.00          0.00000
    MASS(KG/HR   )           164447.          164447.          0.00000
    ENTHALPY(CAL/SEC )       46748.7          60395.2        -0.225954

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

                      ***  INPUT DATA  ***

ISENTROPIC CENTRIFUGAL COMPRESSOR
NUMBER OF STAGES                                           3
FINAL PRESSURE, ATM                                        8.77793
DISTRIBUTION AMONG STAGES                                 EQUAL P-RATIO

                 COMPRESSOR SPECIFICATIONS PER STAGE

STAGE                     MECHANICAL      ISENTROPIC
NUMBER                    EFFICIENCY      EFFICIENCY


  1                          1.000          0.7200
  2                          1.000          0.7200
  3                          1.000          0.7200

                 COOLER SPECIFICATIONS PER STAGE

STAGE     PRESSURE DROP     TEMPERATURE
NUMBER    ATM               K

  1       0.000             305.4
  2       0.000             305.4
  3       0.000             305.4

                       ***  RESULTS  ***

FINAL PRESSURE, ATM                                         8.77793
TOTAL WORK REQUIRED, KW                                13,443.1
TOTAL COOLING DUTY , CAL/SEC                       -3,197,180.

                       ***  PROFILE  ***

                       COMPRESSOR PROFILE

STAGE      OUTLET       PRESSURE      OUTLET
NUMBER     PRESSURE     RATIO         TEMPERATURE
           ATM                        K

  1        2.063        2.063         398.5
  2        4.256        2.063         402.1
```

```
   3        8.778        2.063        402.0

 STAGE      INDICATED      BRAKE
 NUMBER     HORSEPOWER     HORSEPOWER
            KW             KW
   1        4450.          4450.
   2        4494.          4494.
   3        4499.          4499.

 STAGE      HEAD           VOLUMETRIC    ISENTROPIC
 NUMBER     DEVELOPED      FLOW          EFFICIENCY
            M-KGF/KG       L/MIN
   1        7153.         0.2358E+07     0.7200
   2        7223.         0.1154E+07     0.7200
   3        7231.         0.5597E+06     0.7200

                        COOLER PROFILE

 STAGE      OUTLET          OUTLET       COOLING      VAPOR
 NUMBER     TEMPERATURE     PRESSURE     LOAD         FRACTION
            K               ATM          CAL/SEC

   1         305.4           2.063       -.1035E+07   1.000
   2         305.4           4.256       -.1078E+07   1.000
   3         305.4           8.778       -.1084E+07   1.000

BLOCK:  N2VALVE  MODEL: VALVE
-----------------------------
  INLET STREAM:          210
  OUTLET STREAM:         211
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )          3450.00         3450.00         0.00000
      MASS(KG/HR   )          96686.1         96686.1         0.00000
      ENTHALPY(CAL/SEC )     -0.140942E+07   -0.140942E+07     0.00000

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

                        ***  INPUT DATA  ***

   VALVE OUTLET PRESSURE     ATM                             1.36092
   VALVE FLOW COEF CALC.                                   NO

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

                        ***  RESULTS  ***

   VALVE PRESSURE DROP       ATM                             7.14483
```

```
BLOCK:  O2VALVE  MODEL: VALVE
-----------------------------
  INLET STREAM:           207
  OUTLET STREAM:          208
  PROPERTY OPTION SET:    PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )           2250.00         2250.00         0.00000
      MASS(KG/HR   )           67761.2         67761.2         0.00000
      ENTHALPY(CAL/SEC )     -0.165708E+07   -0.165708E+07     0.00000

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

                        ***  INPUT DATA  ***

   VALVE OUTLET PRESSURE     ATM                           1.36092
   VALVE FLOW COEF CALC.                                 NO

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

                        ***  RESULTS  ***

   VALVE PRESSURE DROP       ATM                           7.34080

BLOCK:  PCOND    MODEL: HEATER
------------------------------
  INLET STREAM:           208
  OUTLET STREAM:          209
  PROPERTY OPTION SET:    PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )           2250.00         2250.00         0.00000
      MASS(KG/HR   )           67761.2         67761.2         0.00000
      ENTHALPY(CAL/SEC )     -0.165708E+07    -104223.       -0.937105

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

                        ***  INPUT DATA  ***
  TWO    PHASE  PQ  FLASH
  PRESSURE DROP                       ATM                        0.0
  SPECIFIED HEAT DUTY                 CAL/SEC          1,552,860.
```

```
  MAXIMUM NO. ITERATIONS                                          30
  CONVERGENCE TOLERANCE                                            0.000100000



                        ***  RESULTS  ***
  OUTLET TEMPERATURE    K                                     274.66
  OUTLET PRESSURE       ATM                                   1.3609
  OUTLET VAPOR FRACTION                                       1.0000



  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     OXYGEN           0.52759       0.52759       0.52759       MISSING
     NITROGEN         0.47241       0.47241       0.47241       MISSING

BLOCK:  RECCOMP  MODEL: MCOMPR
------------------------------
  INLET STREAMS:    212          TO STAGE   1
  OUTLET STREAMS:   213        FROM STAGE   3
  PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )          2250.00          2250.00       -0.311160E-06
      MASS(KG/HR   )          67761.2          67761.2       -0.288809E-06
      ENTHALPY(CAL/SEC )      25557.0          22721.8        0.110936

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

                       ***  INPUT DATA  ***

  ISENTROPIC CENTRIFUGAL COMPRESSOR
  NUMBER OF STAGES                                               3
  FINAL PRESSURE, ATM                                            8.84598
  DISTRIBUTION AMONG STAGES                                     EQUAL P-RATIO

                     COMPRESSOR SPECIFICATIONS PER STAGE

  STAGE                      MECHANICAL      ISENTROPIC
  NUMBER                     EFFICIENCY      EFFICIENCY


    1                          1.000          0.7200
    2                          1.000          0.7200
    3                          1.000          0.7200

                     COOLER SPECIFICATIONS PER STAGE

  STAGE     PRESSURE DROP     TEMPERATURE
  NUMBER    ATM               K
```

1	0.000	305.4
2	0.000	305.4
3	0.000	305.4

*** RESULTS ***

FINAL PRESSURE, ATM	8.84598
TOTAL WORK REQUIRED, KW	4,789.49
TOTAL COOLING DUTY , CAL/SEC	-1,146,780.

*** PROFILE ***

COMPRESSOR PROFILE

STAGE NUMBER	OUTLET PRESSURE ATM	PRESSURE RATIO	OUTLET TEMPERATURE K
1	2.368	1.933	390.8
2	4.576	1.933	392.1
3	8.846	1.933	392.1

STAGE NUMBER	INDICATED HORSEPOWER KW	BRAKE HORSEPOWER KW
1	1592.	1592.
2	1598.	1598.
3	1599.	1599.

STAGE NUMBER	HEAD DEVELOPED M-KGF/KG	VOLUMETRIC FLOW L/MIN	ISENTROPIC EFFICIENCY
1	6210.	0.7644E+06	0.7200
2	6234.	0.3969E+06	0.7200
3	6238.	0.2053E+06	0.7200

COOLER PROFILE

STAGE NUMBER	OUTLET TEMPERATURE K	OUTLET PRESSURE ATM	COOLING LOAD CAL/SEC	VAPOR FRACTION
1	305.4	2.368	-.3766E+06	1.000
2	305.4	4.576	-.3839E+06	1.000
3	305.4	8.846	-.3862E+06	1.000

BLOCK: REVALVE MODEL: VALVE

INLET STREAM: 206
OUTLET STREAM: 216
PROPERTY OPTION SET: PSRK RKS-MHV1 EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	2250.00	2250.00	0.00000
MASS(KG/HR)	67761.2	67761.2	0.00000
ENTHALPY(CAL/SEC)	-0.165708E+07	-0.165708E+07	0.00000

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

                        ***  INPUT DATA  ***

    VALVE OUTLET PRESSURE     ATM                            1.36092
    VALVE FLOW COEF CALC.                                  NO

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

                        ***  RESULTS  ***

    VALVE PRESSURE DROP       ATM                            7.34080

 BLOCK:  SPLIT    MODEL: FSPLIT
 ------------------------------
   INLET STREAM:          205
   OUTLET STREAMS:        207         206
   PROPERTY OPTION SET:   PSRK      RKS-MHV1 EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           4500.00         4500.00         0.00000
       MASS(KG/HR   )           135522.         135522.         0.00000
       ENTHALPY(CAL/SEC )     -0.331417E+07   -0.331417E+07     0.00000

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

                        ***  INPUT DATA  ***

  FRACTION OF FLOW                STRM=206      FRAC=        0.50000

                         ***  RESULTS  ***

  STREAM= 207           SPLIT=          0.50000     KEY=  0    STREAM-ORDER=   2
          206                           0.50000           0                    1
```

Stream Report

```
 201 202 203 204 205
 -------------------
```

STREAM ID	201	202	203	204	205
FROM :	----	MAC	MHX	MHX	COL
TO :	MAC	MHX	COL	COL	SPLIT
CONV. MAX. REL. ERR:	0.0	0.0	0.0	-1.2341-06	0.0
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	MIXED	VAPOR	LIQUID
COMPONENTS: KMOL/HR					
OXYGEN	1197.0000	1197.0000	1197.0000	1187.0727	2374.1454
NITROGEN	4503.0000	4503.0000	4503.0000	1062.9287	2125.8560
WATER	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
KMOL/HR	5700.0000	5700.0000	5700.0000	2250.0014	4500.0014
KG/HR	1.6445+05	1.6445+05	1.6445+05	6.7761+04	1.3552+05
L/MIN	2.3584+06	2.7154+05	7.7617+04	3.3962+04	2770.3376
STATE VARIABLES:					
TEMP K	302.5944	305.3722	105.9278	113.1500	108.1990
PRES ATM	1.0003	8.7779	8.6418	8.7099	8.7017
VFRAC	1.0000	1.0000	0.9820	1.0000	0.0
LFRAC	0.0	0.0	1.7970-02	0.0	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	29.5255	38.1444	-1458.0212	-1379.5128	-2651.3329
CAL/GM	1.0234	1.3221	-50.5373	-45.8065	-88.0371
CAL/SEC	4.6749+04	6.0395+04	-2.3085+06	-8.6220+05	-3.3142+06
ENTROPY:					
CAL/MOL-K	1.1182	-3.1687	-11.2838	-10.2008	-21.7754
CAL/GM-K	3.8759-02	-0.1098	-0.3911	-0.3387	-0.7230
DENSITY:					
MOL/CC	4.0281-05	3.4985-04	1.2240-03	1.1042-03	2.7073-02
GM/CC	1.1621-03	1.0093-02	3.5312-02	3.3253-02	0.8153
AVG MW	28.8504	28.8504	28.8504	30.1161	30.1161

206 207 208 209 210

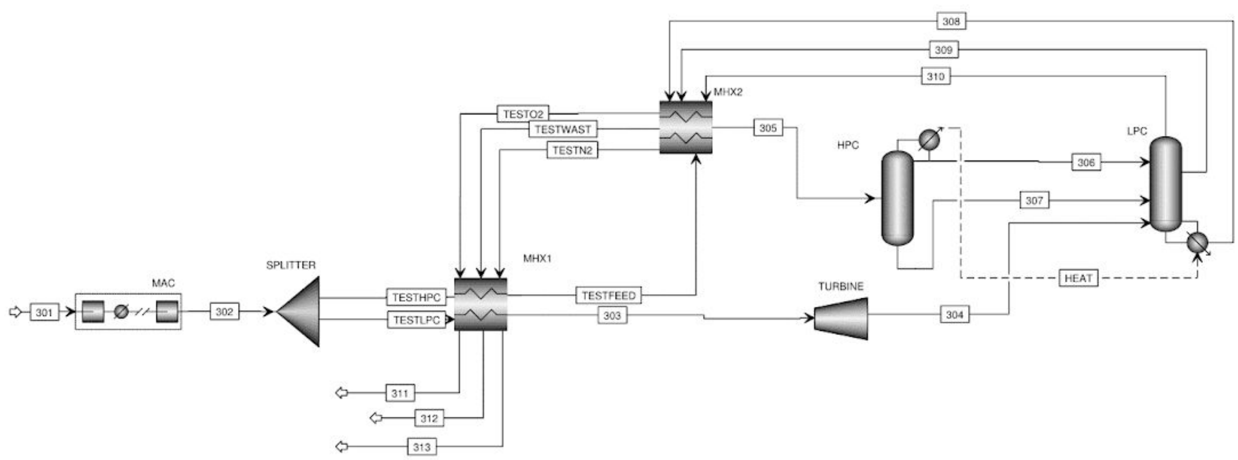
STREAM ID	206	207	208	209	210
FROM :	SPLIT	SPLIT	O2VALVE	PCOND	COL
TO :	REVALVE	O2VALVE	PCOND	MHX	N2VALVE
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	MIXED	VAPOR	VAPOR
COMPONENTS: KMOL/HR					
OXYGEN	1187.0727	1187.0727	1187.0727	1187.0727	9.9273
NITROGEN	1062.9280	1062.9280	1062.9280	1062.9280	3440.0727
WATER	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
KMOL/HR	2250.0007	2250.0007	2250.0007	2250.0007	3450.0000
KG/HR	6.7761+04	6.7761+04	6.7761+04	6.7761+04	9.6686+04
L/MIN	1385.1688	1385.1688	4.3778+04	6.2070+05	4.5746+04
STATE VARIABLES:					
TEMP K	108.1990	108.1990	85.5742	274.6615	101.5561
PRES ATM	8.7017	8.7017	1.3609	1.3609	8.5057
VFRAC	0.0	0.0	0.2316	1.0000	1.0000
LFRAC	1.0000	1.0000	0.7684	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-2651.3329	-2651.3329	-2651.3329	-166.7567	-1470.7015

```
  CAL/GM               -88.0371    -88.0371    -88.0371     -5.5371    -52.4783
  CAL/SEC             -1.6571+06 -1.6571+06 -1.6571+06 -1.0422+05 -1.4094+06
ENTROPY:
  CAL/MOL-K            -21.7754    -21.7754    -21.2655      0.1796    -12.3808
  CAL/GM-K              -0.7230     -0.7230     -0.7061  5.9625-03     -0.4418
DENSITY:
  MOL/CC              2.7073-02  2.7073-02  8.5659-04  6.0416-05  1.2569-03
  GM/CC                  0.8153      0.8153  2.5797-02  1.8195-03  3.5226-02
AVG MW                  30.1161     30.1161     30.1161     30.1161     28.0249

211 212 213 214 215
-------------------

STREAM ID               211        212        213        214        215
FROM :                  N2VALVE    MHX        RECCOMP    MHX        MHX
TO   :                  MHX        RECCOMP    MHX        ----       ----


CONV. MAX. REL. ERR:    0.0      2.1179-05    0.0        0.0        0.0
SUBSTREAM: MIXED
PHASE:                  VAPOR      VAPOR      VAPOR      VAPOR      VAPOR
COMPONENTS: KMOL/HR
  OXYGEN                 9.9273  1187.0727  1187.0727  1187.0727     9.9273
  NITROGEN            3440.0727  1062.9280  1062.9287  1062.9280  3440.0727
  WATER                  0.0        0.0        0.0        0.0        0.0
TOTAL FLOW:
  KMOL/HR             3450.0000  2250.0007  2250.0014  2250.0007  3450.0000
  KG/HR               9.6686+04  6.7761+04  6.7761+04  6.7761+04  9.6686+04
  L/MIN               2.9731+05  7.6440+05  1.0620+05  7.6014+05  1.1725+06
STATE VARIABLES:
  TEMP   K              89.0749    304.2877    305.3722    302.5944    304.2877
  PRES   ATM             1.3609      1.2248      8.8460      1.2248      1.2248
  VFRAC                  1.0000      1.0000      1.0000      1.0000      1.0000
  LFRAC                  0.0        0.0        0.0        0.0        0.0
  SFRAC                  0.0        0.0        0.0        0.0        0.0
ENTHALPY:
  CAL/MOL            -1470.7015     40.8911     36.3548     29.0284     41.1312
  CAL/GM               -52.4783      1.3578      1.2072      0.9639      1.4677
  CAL/SEC             -1.4094+06  2.5557+04  2.2722+04  1.8143+04  3.9417+04
ENTROPY:
  CAL/MOL-K             -9.0912      1.1067     -2.8339      1.0676     -0.2276
  CAL/GM-K              -0.3244  3.6747-02 -9.4099-02  3.5449-02 -8.1203-03
DENSITY:
  MOL/CC              1.9340-04  4.9058-05  3.5312-04  4.9333-05  4.9040-05
  GM/CC               5.4200-03  1.4774-03  1.0635-02  1.4857-03  1.3743-03
AVG MW                  28.0249     30.1161     30.1161     30.1161     28.0249

216 DUMMY DUMMY2
----------------

STREAM ID               216        DUMMY      DUMMY2
FROM :                  REVALVE    ----       COL
TO   :                  MHX        COL        ----

SUBSTREAM: MIXED
PHASE:                  MIXED      MISSING    MISSING
COMPONENTS: KMOL/HR
  OXYGEN              1187.0727      0.0        0.0
  NITROGEN            1062.9280      0.0        0.0
```

WATER	0.0	0.0	0.0
TOTAL FLOW:			
KMOL/HR	2250.0007	0.0	0.0
KG/HR	6.7761+04	0.0	0.0
L/MIN	4.3778+04	0.0	0.0
STATE VARIABLES:			
TEMP K	85.5742	305.3722	MISSING
PRES ATM	1.3609	6.4644	MISSING
VFRAC	0.2316	MISSING	MISSING
LFRAC	0.7684	MISSING	MISSING
SFRAC	0.0	MISSING	MISSING
ENTHALPY:			
CAL/MOL	-2651.3329	MISSING	MISSING
CAL/GM	-88.0371	MISSING	MISSING
CAL/SEC	-1.6571+06	MISSING	MISSING
ENTROPY:			
CAL/MOL-K	-21.2655	MISSING	MISSING
CAL/GM-K	-0.7061	MISSING	MISSING
DENSITY:			
MOL/CC	8.5659-04	MISSING	MISSING
GM/CC	2.5797-02	MISSING	MISSING
AVG MW	30.1161	MISSING	MISSING

95% Oxygen

<u>Flowsheet</u>



In this simulation, two MHEATX blocks were used because, in reality, stream 303 would split from 302 in the middle of a single heat exchanger and only travel through about half of the exchanger. It was simpler to model on ASPEN using two blocks, where stream 303 only went through one heat exchanger.

Block Report

```
 BLOCK:  MHX1     MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 TESTHPC          TESTFEED
                 TESTLPC          303

   COLD SIDE:    INLET STREAM     OUTLET STREAM
                 ------------     -------------
                 TESTN2           313
                 TESTO2           311
                 TESTWAST         312

   PROPERTIES FOR STREAM TESTLPC
   PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTN2
   PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTO2
   PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTWAST
   PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTHPC
   PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)           26455.5         26455.5         0.00000
       MASS(LB/HR   )           763251.         763251.        0.152526E-15
       ENTHALPY(BTU/HR  )      -0.225144E+08   -0.225144E+08   -0.165463E-15

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

                        ***  INPUT DATA  ***


   SPECIFICATIONS FOR STREAM TESTLPC :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               F                      -150.000
   SPECIFIED PRESSURE                  PSIA                    102.000
   MAXIMUM NO. ITERATIONS                                       50
   CONVERGENCE TOLERANCE                                         0.000100000

   SPECIFICATIONS FOR STREAM TESTN2  :
   TWO    PHASE  TP  FLASH
```

```
 SPECIFIED TEMPERATURE              F                        80.0000
 SPECIFIED PRESSURE                 PSIA                     23.0000
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTO2   :
 TWO    PHASE   TP  FLASH
 SPECIFIED TEMPERATURE              F                        80.0000
 SPECIFIED PRESSURE                 PSIA                     23.0000
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTWAST:
 TWO    PHASE   TP  FLASH
 SPECIFIED TEMPERATURE              F                        80.0000
 PRESSURE DROP                      PSI                       0.0
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTHPC :
 TWO    PHASE       FLASH
 PRESSURE DROP                      PSI                       0.0
 MAXIMUM NO. ITERATIONS                                      50
 CONVERGENCE TOLERANCE                                        0.000100000

                       ***  RESULTS  ***

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

TESTLPC   -0.46189E+07   -150.00      102.00        1.0000
TESTN2     0.11601E+08     80.00      23.000        1.0000
TESTO2     0.42911E+07     80.00      23.000        1.0000
TESTWAST   0.81886E+07     80.00      23.720        1.0000
TESTHPC   -0.19461E+08   -162.76      102.00        1.0000


         ------------------------------------------
         |                                        |
TESTN2   |                                        | 313
--------->|         6377.7     LBMOL/HR           |--------->
  -180.00 |                                       |    80.00
         |                                        |
TESTO2   |                                        | 311
--------->|         2350.0     LBMOL/HR           |--------->
  -180.00 |                                       |    80.00
         |                                        |
TESTWAST |                                        | 312
--------->|         4500.0     LBMOL/HR           |--------->
  -180.00 |                                       |    80.00
         |                                        |
303      |                                        | TESTLPC
<---------|         2645.5     LBMOL/HR           |<---------
  -150.00 |                                       |    95.00
         |                                        |
TESTFEED |                                        | TESTHPC
<---------|         10582.     LBMOL/HR           |<---------
  -162.76 |                                       |    95.00
```

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

```
MHEATX HCURVE:      MHX1     HCURVE 2
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTLPC
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	102.0000	95.0000	1.0000
-4.1990+05	102.0000	72.5120	1.0000
-8.3980+05	102.0000	50.0403	1.0000
-1.2597+06	102.0000	27.5914	1.0000
-1.6796+06	102.0000	5.1726	1.0000
-2.0995+06	102.0000	-17.2078	1.0000
-2.5194+06	102.0000	-39.5406	1.0000
-2.9393+06	102.0000	-61.8147	1.0000
-3.3592+06	102.0000	-84.0165	1.0000
-3.7791+06	102.0000	-106.1297	1.0000
-4.1990+06	102.0000	-128.1333	1.0000
-4.6189+06	102.0000	-150.0000	1.0000

```
MHEATX HCURVE:      MHX1     HCURVE 3
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTN2
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	23.0000	-180.0000	1.0000
1.0546+06	23.0000	-156.4874	1.0000
2.1092+06	23.0000	-132.9315	1.0000
3.1638+06	23.0000	-109.3417	1.0000
4.2184+06	23.0000	-85.7249	1.0000
5.2730+06	23.0000	-62.0866	1.0000
6.3276+06	23.0000	-38.4309	1.0000

7.3822+06	23.0000	-14.7613	1.0000
8.4368+06	23.0000	8.9192	1.0000
9.4914+06	23.0000	32.6079	1.0000
1.0546+07	23.0000	56.3023	1.0000
1.1601+07	23.0000	80.0000	1.0000

MHEATX HCURVE: MHX1 HCURVE 4

INDEPENDENT VARIABLE: DUTY
STREAM: TESTO2
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	23.0000	-180.4747	1.0000
3.9010+05	23.0000	-156.8737	1.0000
7.8019+05	23.0000	-133.2302	1.0000
1.1703+06	23.0000	-109.5549	1.0000
1.5604+06	23.0000	-85.8568	1.0000
1.9505+06	23.0000	-62.1440	1.0000
2.3406+06	23.0000	-38.4243	1.0000
2.7307+06	23.0000	-14.7055	1.0000
3.1208+06	23.0000	9.0044	1.0000
3.5109+06	23.0000	32.6973	1.0000
3.9010+06	23.0000	56.3653	1.0000
4.2911+06	23.0000	80.0000	1.0000

MHEATX HCURVE: MHX1 HCURVE 1

INDEPENDENT VARIABLE: DUTY
STREAM: TESTHPC
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	102.0000	95.0000	1.0000
-1.7692+06	102.0000	71.3126	1.0000
-3.5384+06	102.0000	47.6436	1.0000
-5.3076+06	102.0000	24.0007	1.0000
-7.0769+06	102.0000	0.3927	1.0000

```
!------------+------------+------------+------------!
! -8.8461+06 !   102.0000 !   -23.1708 !     1.0000 !
! -1.0615+07 !   102.0000 !   -46.6782 !     1.0000 !
! -1.2385+07 !   102.0000 !   -70.1160 !     1.0000 !
! -1.4154+07 !   102.0000 !   -93.4673 !     1.0000 !
! -1.5923+07 !   102.0000 !  -116.7109 !     1.0000 !
!------------+------------+------------+------------!
! -1.7692+07 !   102.0000 !  -139.8194 !     1.0000 !
! -1.9461+07 !   102.0000 !  -162.7559 !     1.0000 !
-----------------------------------------------------

BLOCK:  MHX1     MODEL: MHEATX
------------------------------

  HOT SIDE:     INLET STREAM     OUTLET STREAM
                ------------     -------------
                TESTHPC          TESTFEED
                TESTLPC          303

  COLD SIDE:    INLET STREAM     OUTLET STREAM
                ------------     -------------
                TESTN2           313
                TESTO2           311
                TESTWAST         312

  PROPERTIES FOR STREAM TESTLPC
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTN2
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTO2
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTWAST
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTHPC
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            26455.5         26455.5         0.00000
      MASS(LB/HR   )            763251.         763251.        0.152526E-15
      ENTHALPY(BTU/HR  )      -0.225144E+08   -0.225144E+08   -0.165463E-15

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

                          ***  INPUT DATA  ***


  SPECIFICATIONS FOR STREAM TESTLPC :
  TWO    PHASE  TP  FLASH
```

```
 SPECIFIED TEMPERATURE              F                     -150.000
 SPECIFIED PRESSURE                 PSIA                   102.000
 MAXIMUM NO. ITERATIONS                                     50
 CONVERGENCE TOLERANCE                                       0.000100000

 SPECIFICATIONS FOR STREAM TESTN2  :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE              F                       80.0000
 SPECIFIED PRESSURE                 PSIA                    23.0000
 MAXIMUM NO. ITERATIONS                                     30
 CONVERGENCE TOLERANCE                                       0.000100000

 SPECIFICATIONS FOR STREAM TESTO2  :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE              F                       80.0000
 SPECIFIED PRESSURE                 PSIA                    23.0000
 MAXIMUM NO. ITERATIONS                                     30
 CONVERGENCE TOLERANCE                                       0.000100000

 SPECIFICATIONS FOR STREAM TESTWAST:
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE              F                       80.0000
 PRESSURE DROP                      PSI                      0.0
 MAXIMUM NO. ITERATIONS                                     30
 CONVERGENCE TOLERANCE                                       0.000100000

 SPECIFICATIONS FOR STREAM TESTHPC :
 TWO    PHASE      FLASH
 PRESSURE DROP                      PSI                      0.0
 MAXIMUM NO. ITERATIONS                                     50
 CONVERGENCE TOLERANCE                                       0.000100000

                         ***  RESULTS  ***

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

TESTLPC   -0.46189E+07   -150.00      102.00        1.0000
TESTN2     0.11601E+08     80.00      23.000        1.0000
TESTO2     0.42911E+07     80.00      23.000        1.0000
TESTWAST   0.81886E+07     80.00      23.720        1.0000
TESTHPC   -0.19461E+08   -162.76      102.00        1.0000


          ------------------------------------------
          |                                        |
TESTN2    |                                        | 313
--------->|         6377.7     LBMOL/HR            |--------->
  -180.00 |                                        |    80.00
          |                                        |
TESTO2    |                                        | 311
--------->|         2350.0     LBMOL/HR            |--------->
  -180.00 |                                        |    80.00
          |                                        |
TESTWAST  |                                        | 312
--------->|         4500.0     LBMOL/HR            |--------->
  -180.00 |                                        |    80.00
          |                                        |
```

```
 303      |                                        | TESTLPC
<---------|        2645.5     LBMOL/HR            |<---------
  -150.00 |                                        |    95.00
          |                                        |
 TESTFEED |                                        | TESTHPC
<---------|        10582.     LBMOL/HR            |<---------
  -162.76 |                                        |    95.00
          |                                        |
          ------------------------------------------
```

```
MHEATX HCURVE:      MHX1     HCURVE 2
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTLPC
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	102.0000	95.0000	1.0000
-4.1990+05	102.0000	72.5120	1.0000
-8.3980+05	102.0000	50.0403	1.0000
-1.2597+06	102.0000	27.5914	1.0000
-1.6796+06	102.0000	5.1726	1.0000
-2.0995+06	102.0000	-17.2078	1.0000
-2.5194+06	102.0000	-39.5406	1.0000
-2.9393+06	102.0000	-61.8147	1.0000
-3.3592+06	102.0000	-84.0165	1.0000
-3.7791+06	102.0000	-106.1297	1.0000
-4.1990+06	102.0000	-128.1333	1.0000
-4.6189+06	102.0000	-150.0000	1.0000

```
MHEATX HCURVE:      MHX1     HCURVE 3
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTN2
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	23.0000	-180.0000	1.0000

```
 !  1.0546+06 !    23.0000 !  -156.4874 !     1.0000 !
 !  2.1092+06 !    23.0000 !  -132.9315 !     1.0000 !
 !  3.1638+06 !    23.0000 !  -109.3417 !     1.0000 !
 !  4.2184+06 !    23.0000 !   -85.7249 !     1.0000 !
 !------------+------------+------------+------------!
 !  5.2730+06 !    23.0000 !   -62.0866 !     1.0000 !
 !  6.3276+06 !    23.0000 !   -38.4309 !     1.0000 !
 !  7.3822+06 !    23.0000 !   -14.7613 !     1.0000 !
 !  8.4368+06 !    23.0000 !     8.9192 !     1.0000 !
 !  9.4914+06 !    23.0000 !    32.6079 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.0546+07 !    23.0000 !    56.3023 !     1.0000 !
 !  1.1601+07 !    23.0000 !    80.0000 !     1.0000 !
 ----------------------------------------------------

MHEATX HCURVE:      MHX1     HCURVE 4
------------------------------------
   INDEPENDENT VARIABLE:  DUTY
   STREAM:                TESTO2
   PRESSURE PROFILE:      CONSTANT
   PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

 ----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  F         !            !
 !            !            !            !            !
 !============!============!============!============!
 !     0.0    !    23.0000 !  -180.4747 !     1.0000 !
 !  3.9010+05 !    23.0000 !  -156.8737 !     1.0000 !
 !  7.8019+05 !    23.0000 !  -133.2302 !     1.0000 !
 !  1.1703+06 !    23.0000 !  -109.5549 !     1.0000 !
 !  1.5604+06 !    23.0000 !   -85.8568 !     1.0000 !
 !------------+------------+------------+------------!
 !  1.9505+06 !    23.0000 !   -62.1440 !     1.0000 !
 !  2.3406+06 !    23.0000 !   -38.4243 !     1.0000 !
 !  2.7307+06 !    23.0000 !   -14.7055 !     1.0000 !
 !  3.1208+06 !    23.0000 !     9.0044 !     1.0000 !
 !  3.5109+06 !    23.0000 !    32.6973 !     1.0000 !
 !------------+------------+------------+------------!
 !  3.9010+06 !    23.0000 !    56.3653 !     1.0000 !
 !  4.2911+06 !    23.0000 !    80.0000 !     1.0000 !
 ----------------------------------------------------

MHEATX HCURVE:      MHX1     HCURVE 1
------------------------------------
   INDEPENDENT VARIABLE:  DUTY
   STREAM:                TESTHPC
   PRESSURE PROFILE:      CONSTANT
   PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

 ----------------------------------------------------
 !  DUTY      !  PRES      !  TEMP      !  VFRAC     !
 !            !            !            !            !
 !            !            !            !            !
 !            !            !            !            !
 !  BTU/HR    !  PSIA      !  F         !            !
```

```
!            !            !            !            !
!============!============!============!============!
!     0.0    !   102.0000 !    95.0000 !     1.0000 !
! -1.7692+06 !   102.0000 !    71.3126 !     1.0000 !
! -3.5384+06 !   102.0000 !    47.6436 !     1.0000 !
! -5.3076+06 !   102.0000 !    24.0007 !     1.0000 !
! -7.0769+06 !   102.0000 !     0.3927 !     1.0000 !
!------------+------------+------------+------------!
! -8.8461+06 !   102.0000 !   -23.1708 !     1.0000 !
! -1.0615+07 !   102.0000 !   -46.6782 !     1.0000 !
! -1.2385+07 !   102.0000 !   -70.1160 !     1.0000 !
! -1.4154+07 !   102.0000 !   -93.4673 !     1.0000 !
! -1.5923+07 !   102.0000 !  -116.7109 !     1.0000 !
!------------+------------+------------+------------!
! -1.7692+07 !   102.0000 !  -139.8194 !     1.0000 !
! -1.9461+07 !   102.0000 !  -162.7559 !     1.0000 !
-----------------------------------------------------

BLOCK:  MHX1     MODEL: MHEATX
------------------------------

  HOT SIDE:    INLET STREAM     OUTLET STREAM
               ------------     -------------
               TESTHPC          TESTFEED
               TESTLPC          303

  COLD SIDE:   INLET STREAM     OUTLET STREAM
               ------------     -------------
               TESTN2           313
               TESTO2           311
               TESTWAST         312

  PROPERTIES FOR STREAM TESTLPC
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTN2
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTO2
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTWAST
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTHPC
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           26455.5         26455.5         0.00000
      MASS(LB/HR    )          763251.         763251.        0.152526E-15
      ENTHALPY(BTU/HR  )     -0.225144E+08   -0.225144E+08   -0.165463E-15

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

```
 TOTAL CO2E PRODUCTION          0.00000      LB/HR

                      ***  INPUT DATA  ***


 SPECIFICATIONS FOR STREAM TESTLPC :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE              F                      -150.000
 SPECIFIED PRESSURE                 PSIA                    102.000
 MAXIMUM NO. ITERATIONS                                      50
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTN2  :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE              F                        80.0000
 SPECIFIED PRESSURE                 PSIA                     23.0000
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTO2  :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE              F                        80.0000
 SPECIFIED PRESSURE                 PSIA                     23.0000
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTWAST:
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE              F                        80.0000
 PRESSURE DROP                      PSI                       0.0
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTHPC :
 TWO    PHASE      FLASH
 PRESSURE DROP                      PSI                       0.0
 MAXIMUM NO. ITERATIONS                                      50
 CONVERGENCE TOLERANCE                                        0.000100000

                      ***  RESULTS  ***

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

TESTLPC   -0.46189E+07   -150.00      102.00        1.0000
TESTN2     0.11601E+08     80.00      23.000        1.0000
TESTO2     0.42911E+07     80.00      23.000        1.0000
TESTWAST   0.81886E+07     80.00      23.720        1.0000
TESTHPC   -0.19461E+08   -162.76      102.00        1.0000


         ------------------------------------------
         |                                        |
TESTN2   |                                        | 313
--------->|          6377.7     LBMOL/HR          |--------->
  -180.00 |                                       |    80.00
         |                                        |
TESTO2   |                                        | 311
```

```
---------->|          2350.0     LBMOL/HR          |--------->
  -180.00  |                                       |    80.00
           |                                       |
 TESTWAST  |                                       | 312
---------->|          4500.0     LBMOL/HR          |--------->
  -180.00  |                                       |    80.00
           |                                       |
 303       |                                       | TESTLPC
<----------|          2645.5     LBMOL/HR          |<---------
  -150.00  |                                       |    95.00
           |                                       |
 TESTFEED  |                                       | TESTHPC
<----------|          10582.     LBMOL/HR          |<---------
  -162.76  |                                       |    95.00
           |                                       |
           -----------------------------------------
```

```
MHEATX HCURVE:      MHX1     HCURVE 2
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTLPC
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	102.0000	95.0000	1.0000
-4.1990+05	102.0000	72.5120	1.0000
-8.3980+05	102.0000	50.0403	1.0000
-1.2597+06	102.0000	27.5914	1.0000
-1.6796+06	102.0000	5.1726	1.0000
-2.0995+06	102.0000	-17.2078	1.0000
-2.5194+06	102.0000	-39.5406	1.0000
-2.9393+06	102.0000	-61.8147	1.0000
-3.3592+06	102.0000	-84.0165	1.0000
-3.7791+06	102.0000	-106.1297	1.0000
-4.1990+06	102.0000	-128.1333	1.0000
-4.6189+06	102.0000	-150.0000	1.0000

```
MHEATX HCURVE:      MHX1     HCURVE 3
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTN2
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
```

DUTY	PRES	TEMP	VFRAC

BTU/HR	PSIA	F	
0.0	23.0000	-180.0000	1.0000
1.0546+06	23.0000	-156.4874	1.0000
2.1092+06	23.0000	-132.9315	1.0000
3.1638+06	23.0000	-109.3417	1.0000
4.2184+06	23.0000	-85.7249	1.0000
5.2730+06	23.0000	-62.0866	1.0000
6.3276+06	23.0000	-38.4309	1.0000
7.3822+06	23.0000	-14.7613	1.0000
8.4368+06	23.0000	8.9192	1.0000
9.4914+06	23.0000	32.6079	1.0000
1.0546+07	23.0000	56.3023	1.0000
1.1601+07	23.0000	80.0000	1.0000

MHEATX HCURVE: MHX1 HCURVE 4

INDEPENDENT VARIABLE: DUTY
STREAM: TESTO2
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	23.0000	-180.4747	1.0000
3.9010+05	23.0000	-156.8737	1.0000
7.8019+05	23.0000	-133.2302	1.0000
1.1703+06	23.0000	-109.5549	1.0000
1.5604+06	23.0000	-85.8568	1.0000
1.9505+06	23.0000	-62.1440	1.0000
2.3406+06	23.0000	-38.4243	1.0000
2.7307+06	23.0000	-14.7055	1.0000
3.1208+06	23.0000	9.0044	1.0000
3.5109+06	23.0000	32.6973	1.0000
3.9010+06	23.0000	56.3653	1.0000
4.2911+06	23.0000	80.0000	1.0000

MHEATX HCURVE: MHX1 HCURVE 1

INDEPENDENT VARIABLE: DUTY
STREAM: TESTHPC
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

```
 ----------------------------------------------------
 !  DUTY       !  PRES       !  TEMP       !  VFRAC      !
 !             !             !             !             !
 !             !             !             !             !
 !             !             !             !             !
 !  BTU/HR     !  PSIA       !  F          !             !
 !             !             !             !             !
 !============!============!============!============!
 !      0.0    !   102.0000 !    95.0000 !     1.0000 !
 ! -1.7692+06 !   102.0000 !    71.3126 !     1.0000 !
 ! -3.5384+06 !   102.0000 !    47.6436 !     1.0000 !
 ! -5.3076+06 !   102.0000 !    24.0007 !     1.0000 !
 ! -7.0769+06 !   102.0000 !     0.3927 !     1.0000 !
 !------------+------------+------------+------------!
 ! -8.8461+06 !   102.0000 !   -23.1708 !     1.0000 !
 ! -1.0615+07 !   102.0000 !   -46.6782 !     1.0000 !
 ! -1.2385+07 !   102.0000 !   -70.1160 !     1.0000 !
 ! -1.4154+07 !   102.0000 !   -93.4673 !     1.0000 !
 ! -1.5923+07 !   102.0000 !  -116.7109 !     1.0000 !
 !------------+------------+------------+------------!
 ! -1.7692+07 !   102.0000 !  -139.8194 !     1.0000 !
 ! -1.9461+07 !   102.0000 !  -162.7559 !     1.0000 !
 ----------------------------------------------------

 BLOCK:  MHX1     MODEL: MHEATX
 ------------------------------

   HOT SIDE:     INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 TESTHPC           TESTFEED
                 TESTLPC           303

   COLD SIDE:    INLET STREAM      OUTLET STREAM
                 ------------      -------------
                 TESTN2            313
                 TESTO2            311
                 TESTWAST          312

   PROPERTIES FOR STREAM TESTLPC
   PROPERTY OPTION SET:   PENG-ROB   STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTN2
   PROPERTY OPTION SET:   PENG-ROB   STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTO2
   PROPERTY OPTION SET:   PENG-ROB   STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTWAST
   PROPERTY OPTION SET:   PENG-ROB   STANDARD PR EQUATION OF STATE

   PROPERTIES FOR STREAM TESTHPC
   PROPERTY OPTION SET:   PENG-ROB   STANDARD PR EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT          RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(LBMOL/HR)          26455.5          26455.5           0.00000
       MASS(LB/HR   )          763251.          763251.          0.152526E-15
```

```
   ENTHALPY(BTU/HR  )      -0.225144E+08   -0.225144E+08   -0.165463E-15

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

                        ***  INPUT DATA  ***


 SPECIFICATIONS FOR STREAM TESTLPC :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE            F                        -150.000
 SPECIFIED PRESSURE               PSIA                      102.000
 MAXIMUM NO. ITERATIONS                                      50
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTN2  :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE            F                          80.0000
 SPECIFIED PRESSURE               PSIA                       23.0000
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTO2  :
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE            F                          80.0000
 SPECIFIED PRESSURE               PSIA                       23.0000
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTWAST:
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE            F                          80.0000
 PRESSURE DROP                    PSI                         0.0
 MAXIMUM NO. ITERATIONS                                      30
 CONVERGENCE TOLERANCE                                        0.000100000

 SPECIFICATIONS FOR STREAM TESTHPC :
 TWO    PHASE      FLASH
 PRESSURE DROP                    PSI                         0.0
 MAXIMUM NO. ITERATIONS                                      50
 CONVERGENCE TOLERANCE                                        0.000100000

                        ***  RESULTS  ***

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

TESTLPC   -0.46189E+07   -150.00      102.00        1.0000
TESTN2     0.11601E+08     80.00      23.000        1.0000
TESTO2     0.42911E+07     80.00      23.000        1.0000
TESTWAST   0.81886E+07     80.00      23.720        1.0000
TESTHPC   -0.19461E+08   -162.76      102.00        1.0000
```

```
          ------------------------------------------
          |                                        |
 TESTN2   |                                        | 313
--------->|        6377.7     LBMOL/HR             |--------->
  -180.00 |                                        |    80.00
          |                                        |
 TESTO2   |                                        | 311
--------->|        2350.0     LBMOL/HR             |--------->
  -180.00 |                                        |    80.00
          |                                        |
 TESTWAST |                                        | 312
--------->|        4500.0     LBMOL/HR             |--------->
  -180.00 |                                        |    80.00
          |                                        |
 303      |                                        | TESTLPC
<---------|        2645.5     LBMOL/HR             |<---------
  -150.00 |                                        |    95.00
          |                                        |
 TESTFEED |                                        | TESTHPC
<---------|        10582.     LBMOL/HR             |<---------
  -162.76 |                                        |    95.00
          |                                        |
          ------------------------------------------
```

```
MHEATX HCURVE:      MHX1     HCURVE 2
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTLPC
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	102.0000	95.0000	1.0000
-4.1990+05	102.0000	72.5120	1.0000
-8.3980+05	102.0000	50.0403	1.0000
-1.2597+06	102.0000	27.5914	1.0000
-1.6796+06	102.0000	5.1726	1.0000
-2.0995+06	102.0000	-17.2078	1.0000
-2.5194+06	102.0000	-39.5406	1.0000
-2.9393+06	102.0000	-61.8147	1.0000
-3.3592+06	102.0000	-84.0165	1.0000
-3.7791+06	102.0000	-106.1297	1.0000
-4.1990+06	102.0000	-128.1333	1.0000
-4.6189+06	102.0000	-150.0000	1.0000

```
MHEATX HCURVE:      MHX1     HCURVE 3
-------------------------------------
```

INDEPENDENT VARIABLE: DUTY
STREAM: TESTN2
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	23.0000	-180.0000	1.0000
1.0546+06	23.0000	-156.4874	1.0000
2.1092+06	23.0000	-132.9315	1.0000
3.1638+06	23.0000	-109.3417	1.0000
4.2184+06	23.0000	-85.7249	1.0000
5.2730+06	23.0000	-62.0866	1.0000
6.3276+06	23.0000	-38.4309	1.0000
7.3822+06	23.0000	-14.7613	1.0000
8.4368+06	23.0000	8.9192	1.0000
9.4914+06	23.0000	32.6079	1.0000
1.0546+07	23.0000	56.3023	1.0000
1.1601+07	23.0000	80.0000	1.0000

MHEATX HCURVE: MHX1 HCURVE 4

INDEPENDENT VARIABLE: DUTY
STREAM: TESTO2
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	23.0000	-180.4747	1.0000
3.9010+05	23.0000	-156.8737	1.0000
7.8019+05	23.0000	-133.2302	1.0000
1.1703+06	23.0000	-109.5549	1.0000
1.5604+06	23.0000	-85.8568	1.0000
1.9505+06	23.0000	-62.1440	1.0000
2.3406+06	23.0000	-38.4243	1.0000
2.7307+06	23.0000	-14.7055	1.0000
3.1208+06	23.0000	9.0044	1.0000
3.5109+06	23.0000	32.6973	1.0000
3.9010+06	23.0000	56.3653	1.0000
4.2911+06	23.0000	80.0000	1.0000

MHEATX HCURVE: MHX1 HCURVE 1

INDEPENDENT VARIABLE: DUTY
STREAM: TESTHPC
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	102.0000	95.0000	1.0000
-1.7692+06	102.0000	71.3126	1.0000
-3.5384+06	102.0000	47.6436	1.0000
-5.3076+06	102.0000	24.0007	1.0000
-7.0769+06	102.0000	0.3927	1.0000
-8.8461+06	102.0000	-23.1708	1.0000
-1.0615+07	102.0000	-46.6782	1.0000
-1.2385+07	102.0000	-70.1160	1.0000
-1.4154+07	102.0000	-93.4673	1.0000
-1.5923+07	102.0000	-116.7109	1.0000
-1.7692+07	102.0000	-139.8194	1.0000
-1.9461+07	102.0000	-162.7559	1.0000

BLOCK: MHX1 MODEL: MHEATX

	INLET STREAM	OUTLET STREAM
HOT SIDE:	TESTHPC	TESTFEED
	TESTLPC	303
COLD SIDE:	TESTN2	313
	TESTO2	311
	TESTWAST	312

PROPERTIES FOR STREAM TESTLPC
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM TESTN2
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM TESTO2
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM TESTWAST
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM TESTHPC

```
PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN                OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)             26455.5         26455.5         0.00000
    MASS(LB/HR   )             763251.         763251.        0.152526E-15
    ENTHALPY(BTU/HR  )      -0.225144E+08   -0.225144E+08   -0.165463E-15

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

                       ***  INPUT DATA  ***


SPECIFICATIONS FOR STREAM TESTLPC :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                 F                        -150.000
SPECIFIED PRESSURE                    PSIA                      102.000
MAXIMUM NO. ITERATIONS                                           50
CONVERGENCE TOLERANCE                                             0.000100000

SPECIFICATIONS FOR STREAM TESTN2  :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                 F                          80.0000
SPECIFIED PRESSURE                    PSIA                       23.0000
MAXIMUM NO. ITERATIONS                                           30
CONVERGENCE TOLERANCE                                             0.000100000

SPECIFICATIONS FOR STREAM TESTO2  :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                 F                          80.0000
SPECIFIED PRESSURE                    PSIA                       23.0000
MAXIMUM NO. ITERATIONS                                           30
CONVERGENCE TOLERANCE                                             0.000100000

SPECIFICATIONS FOR STREAM TESTWAST:
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                 F                          80.0000
PRESSURE DROP                         PSI                         0.0
MAXIMUM NO. ITERATIONS                                           30
CONVERGENCE TOLERANCE                                             0.000100000

SPECIFICATIONS FOR STREAM TESTHPC :
TWO    PHASE       FLASH
PRESSURE DROP                         PSI                         0.0
MAXIMUM NO. ITERATIONS                                           50
CONVERGENCE TOLERANCE                                             0.000100000

                       ***  RESULTS  ***

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

```
 TESTLPC   -0.46189E+07   -150.00      102.00        1.0000
 TESTN2     0.11601E+08     80.00      23.000        1.0000
 TESTO2     0.42911E+07     80.00      23.000        1.0000
 TESTWAST   0.81886E+07     80.00      23.720        1.0000
 TESTHPC   -0.19461E+08   -162.76      102.00        1.0000


          -----------------------------------------
          |                                       |
 TESTN2   |                                       | 313
--------->|         6377.7     LBMOL/HR           |--------->
  -180.00 |                                       |    80.00
          |                                       |
 TESTO2   |                                       | 311
--------->|         2350.0     LBMOL/HR           |--------->
  -180.00 |                                       |    80.00
          |                                       |
 TESTWAST |                                       | 312
--------->|         4500.0     LBMOL/HR           |--------->
  -180.00 |                                       |    80.00
          |                                       |
 303      |                                       | TESTLPC
<---------|         2645.5     LBMOL/HR           |<---------
  -150.00 |                                       |    95.00
          |                                       |
 TESTFEED |                                       | TESTHPC
<---------|         10582.     LBMOL/HR           |<---------
  -162.76 |                                       |    95.00
          |                                       |
          -----------------------------------------


MHEATX HCURVE:      MHX1     HCURVE 2
------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTLPC
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

-----------------------------------------------------
!  DUTY       !  PRES       !  TEMP       !  VFRAC      !
!             !             !             !             !
!             !             !             !             !
!             !             !             !             !
!  BTU/HR     !  PSIA       !  F          !             !
!             !             !             !             !
!============!============!============!============!
!     0.0     !   102.0000 !    95.0000 !     1.0000 !
! -4.1990+05 !   102.0000 !    72.5120 !     1.0000 !
! -8.3980+05 !   102.0000 !    50.0403 !     1.0000 !
! -1.2597+06 !   102.0000 !    27.5914 !     1.0000 !
! -1.6796+06 !   102.0000 !     5.1726 !     1.0000 !
!------------+------------+------------+------------!
! -2.0995+06 !   102.0000 !   -17.2078 !     1.0000 !
! -2.5194+06 !   102.0000 !   -39.5406 !     1.0000 !
! -2.9393+06 !   102.0000 !   -61.8147 !     1.0000 !
! -3.3592+06 !   102.0000 !   -84.0165 !     1.0000 !
! -3.7791+06 !   102.0000 !  -106.1297 !     1.0000 !
```

```
!------------+------------+------------+------------!
! -4.1990+06 !   102.0000 !  -128.1333 !     1.0000 !
! -4.6189+06 !   102.0000 !  -150.0000 !     1.0000 !
-----------------------------------------------------

MHEATX HCURVE:      MHX1     HCURVE 3
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTN2
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  BTU/HR    !  PSIA      !  F         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    23.0000 !  -180.0000 !     1.0000 !
!  1.0546+06 !    23.0000 !  -156.4874 !     1.0000 !
!  2.1092+06 !    23.0000 !  -132.9315 !     1.0000 !
!  3.1638+06 !    23.0000 !  -109.3417 !     1.0000 !
!  4.2184+06 !    23.0000 !   -85.7249 !     1.0000 !
!------------+------------+------------+------------!
!  5.2730+06 !    23.0000 !   -62.0866 !     1.0000 !
!  6.3276+06 !    23.0000 !   -38.4309 !     1.0000 !
!  7.3822+06 !    23.0000 !   -14.7613 !     1.0000 !
!  8.4368+06 !    23.0000 !     8.9192 !     1.0000 !
!  9.4914+06 !    23.0000 !    32.6079 !     1.0000 !
!------------+------------+------------+------------!
!  1.0546+07 !    23.0000 !    56.3023 !     1.0000 !
!  1.1601+07 !    23.0000 !    80.0000 !     1.0000 !
-----------------------------------------------------

MHEATX HCURVE:      MHX1     HCURVE 4
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTO2
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  BTU/HR    !  PSIA      !  F         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !    23.0000 !  -180.4747 !     1.0000 !
!  3.9010+05 !    23.0000 !  -156.8737 !     1.0000 !
!  7.8019+05 !    23.0000 !  -133.2302 !     1.0000 !
!  1.1703+06 !    23.0000 !  -109.5549 !     1.0000 !
!  1.5604+06 !    23.0000 !   -85.8568 !     1.0000 !
!------------+------------+------------+------------!
!  1.9505+06 !    23.0000 !   -62.1440 !     1.0000 !
!  2.3406+06 !    23.0000 !   -38.4243 !     1.0000 !
```

```
!  2.7307+06 !    23.0000 !   -14.7055 !     1.0000 !
!  3.1208+06 !    23.0000 !     9.0044 !     1.0000 !
!  3.5109+06 !    23.0000 !    32.6973 !     1.0000 !
!------------+------------+------------+------------!
!  3.9010+06 !    23.0000 !    56.3653 !     1.0000 !
!  4.2911+06 !    23.0000 !    80.0000 !     1.0000 !
-----------------------------------------------------

MHEATX HCURVE:      MHX1     HCURVE 1
-------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  STREAM:                TESTHPC
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  BTU/HR    !  PSIA      !  F         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !   102.0000 !    95.0000 !     1.0000 !
! -1.7692+06 !   102.0000 !    71.3126 !     1.0000 !
! -3.5384+06 !   102.0000 !    47.6436 !     1.0000 !
! -5.3076+06 !   102.0000 !    24.0007 !     1.0000 !
! -7.0769+06 !   102.0000 !     0.3927 !     1.0000 !
!------------+------------+------------+------------!
! -8.8461+06 !   102.0000 !   -23.1708 !     1.0000 !
! -1.0615+07 !   102.0000 !   -46.6782 !     1.0000 !
! -1.2385+07 !   102.0000 !   -70.1160 !     1.0000 !
! -1.4154+07 !   102.0000 !   -93.4673 !     1.0000 !
! -1.5923+07 !   102.0000 !  -116.7109 !     1.0000 !
!------------+------------+------------+------------!
! -1.7692+07 !   102.0000 !  -139.8194 !     1.0000 !
! -1.9461+07 !   102.0000 !  -162.7559 !     1.0000 !
-----------------------------------------------------

BLOCK:  MHX2     MODEL: MHEATX
------------------------------

  HOT SIDE:    INLET STREAM     OUTLET STREAM
               ------------     -------------
               TESTFEED         305

  COLD SIDE:   INLET STREAM     OUTLET STREAM
               ------------     -------------
               308              TESTO2
               310              TESTN2
               309              TESTWAST

  PROPERTIES FOR STREAM 308
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM 310
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM 309
```

```
PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM TESTFEED
PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN                OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)           23809.9         23809.9         0.00000
    MASS(LB/HR   )           686926.         686926.       -0.169473E-15
    ENTHALPY(BTU/HR  )      -0.608114E+08   -0.608114E+08     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  ***


SPECIFICATIONS FOR STREAM 308     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                F                        -180.000
PRESSURE DROP                        PSI                         0.0
MAXIMUM NO. ITERATIONS                                          30
CONVERGENCE TOLERANCE                                            0.000100000

SPECIFICATIONS FOR STREAM 310     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                F                        -180.000
PRESSURE DROP                        PSI                         0.0
MAXIMUM NO. ITERATIONS                                          30
CONVERGENCE TOLERANCE                                            0.000100000

SPECIFICATIONS FOR STREAM 309     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                F                        -180.000
PRESSURE DROP                        PSI                         0.0
MAXIMUM NO. ITERATIONS                                          30
CONVERGENCE TOLERANCE                                            0.000100000

SPECIFICATIONS FOR STREAM TESTFEED:
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

308        0.84050E+07   -180.00      27.320        1.0000
310        0.60384E+07   -180.00      23.000        1.0000
309        0.41199E+07   -180.00      23.720        1.0000
TESTFEED  -0.18563E+08   -276.56      102.00        0.5920
```

```
          ------------------------------------------
          |                                        |
 308      |                                        | TESTO2
--------->|         2350.0     LBMOL/HR            |--------->
  -288.74 |                                        |  -180.00
          |                                        |
 310      |                                        | TESTN2
--------->|         6377.7     LBMOL/HR            |--------->
  -312.60 |                                        |  -180.00
          |                                        |
 309      |                                        | TESTWAST
--------->|         4500.0     LBMOL/HR            |--------->
  -308.23 |                                        |  -180.00
          |                                        |
 305      |                                        | TESTFEED
<---------|         10582.     LBMOL/HR            |<---------
  -276.56 |                                        |  -162.76
          |                                        |
          ------------------------------------------
```

```
BLOCK:  MHX2     MODEL: MHEATX
------------------------------

  HOT SIDE:    INLET STREAM     OUTLET STREAM
               ------------     -------------
               TESTFEED         305

  COLD SIDE:   INLET STREAM     OUTLET STREAM
               ------------     -------------
               308              TESTO2
               310              TESTN2
               309              TESTWAST

  PROPERTIES FOR STREAM 308
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM 310
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM 309
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTFEED
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           23809.9         23809.9         0.00000
      MASS(LB/HR   )           686926.         686926.       -0.169473E-15
      ENTHALPY(BTU/HR  )     -0.608114E+08   -0.608114E+08     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  ***


   SPECIFICATIONS FOR STREAM 308     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               F                      -180.000
   PRESSURE DROP                       PSI                       0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000

   SPECIFICATIONS FOR STREAM 310     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               F                      -180.000
   PRESSURE DROP                       PSI                       0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000

   SPECIFICATIONS FOR STREAM 309     :
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               F                      -180.000
   PRESSURE DROP                       PSI                       0.0
   MAXIMUM NO. ITERATIONS                                       30
   CONVERGENCE TOLERANCE                                         0.000100000

   SPECIFICATIONS FOR STREAM TESTFEED:
   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

  308        0.84050E+07   -180.00      27.320        1.0000
  310        0.60384E+07   -180.00      23.000        1.0000
  309        0.41199E+07   -180.00      23.720        1.0000
  TESTFEED  -0.18563E+08   -276.56      102.00        0.5920


           ------------------------------------------
           |                                        |
  308      |                                        | TESTO2
 --------->|          2350.0     LBMOL/HR           |--------->
   -288.74 |                                        |  -180.00
           |                                        |
  310      |                                        | TESTN2
 --------->|          6377.7     LBMOL/HR           |--------->
   -312.60 |                                        |  -180.00
           |                                        |
  309      |                                        | TESTWAST
 --------->|          4500.0     LBMOL/HR           |--------->
   -308.23 |                                        |  -180.00
```

```
         |                                         |
 305     |                                         | TESTFEED
<---------|        10582.     LBMOL/HR             |<---------
  -276.56 |                                        |  -162.76
          |                                        |
          -----------------------------------------
```

```
BLOCK:  MHX2     MODEL: MHEATX
------------------------------

  HOT SIDE:     INLET STREAM     OUTLET STREAM
                ------------     -------------
                TESTFEED         305

  COLD SIDE:    INLET STREAM     OUTLET STREAM
                ------------     -------------
                308              TESTO2
                310              TESTN2
                309              TESTWAST

  PROPERTIES FOR STREAM 308
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM 310
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM 309
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

  PROPERTIES FOR STREAM TESTFEED
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           23809.9         23809.9          0.00000
      MASS(LB/HR   )           686926.         686926.        -0.169473E-15
      ENTHALPY(BTU/HR  )     -0.608114E+08   -0.608114E+08     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  ***


  SPECIFICATIONS FOR STREAM 308      :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE                 F                       -180.000
  PRESSURE DROP                         PSI                        0.0
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                            0.000100000

  SPECIFICATIONS FOR STREAM 310      :
```

```
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              F                         -180.000
  PRESSURE DROP                      PSI                          0.0
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000

  SPECIFICATIONS FOR STREAM 309     :
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              F                         -180.000
  PRESSURE DROP                      PSI                          0.0
  MAXIMUM NO. ITERATIONS                                         30
  CONVERGENCE TOLERANCE                                           0.000100000

  SPECIFICATIONS FOR STREAM TESTFEED:
  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

 308        0.84050E+07   -180.00      27.320        1.0000
 310        0.60384E+07   -180.00      23.000        1.0000
 309        0.41199E+07   -180.00      23.720        1.0000
 TESTFEED  -0.18563E+08   -276.56      102.00        0.5920


          -----------------------------------------
          |                                       |
 308      |                                       | TESTO2
--------->|       2350.0     LBMOL/HR             |--------->
  -288.74 |                                       |  -180.00
          |                                       |
 310      |                                       | TESTN2
--------->|       6377.7     LBMOL/HR             |--------->
  -312.60 |                                       |  -180.00
          |                                       |
 309      |                                       | TESTWAST
--------->|       4500.0     LBMOL/HR             |--------->
  -308.23 |                                       |  -180.00
          |                                       |
 305      |                                       | TESTFEED
<---------|       10582.     LBMOL/HR             |<---------
  -276.56 |                                       |  -162.76
          |                                       |
          -----------------------------------------


BLOCK:  MHX2     MODEL: MHEATX
------------------------------

  HOT SIDE:    INLET STREAM      OUTLET STREAM
               ------------      -------------
               TESTFEED          305
```

```
COLD SIDE:   INLET STREAM     OUTLET STREAM
             ------------     -------------
             308              TESTO2
             310              TESTN2
             309              TESTWAST

PROPERTIES FOR STREAM 308
PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM 310
PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM 309
PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

PROPERTIES FOR STREAM TESTFEED
PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)            23809.9         23809.9        0.00000
    MASS(LB/HR   )            686926.         686926.       -0.169473E-15
    ENTHALPY(BTU/HR  )      -0.608114E+08   -0.608114E+08    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  ***


SPECIFICATIONS FOR STREAM 308     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               F                       -180.000
PRESSURE DROP                       PSI                        0.0
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.000100000

SPECIFICATIONS FOR STREAM 310     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               F                       -180.000
PRESSURE DROP                       PSI                        0.0
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.000100000

SPECIFICATIONS FOR STREAM 309     :
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE               F                       -180.000
PRESSURE DROP                       PSI                        0.0
MAXIMUM NO. ITERATIONS                                        30
CONVERGENCE TOLERANCE                                          0.000100000

SPECIFICATIONS FOR STREAM TESTFEED:
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

 308        0.84050E+07   -180.00      27.320        1.0000
 310        0.60384E+07   -180.00      23.000        1.0000
 309        0.41199E+07   -180.00      23.720        1.0000
 TESTFEED  -0.18563E+08   -276.56      102.00        0.5920


          ------------------------------------------
          |                                        |
 308      |                                        | TESTO2
--------->|         2350.0     LBMOL/HR            |--------->
  -288.74 |                                        |  -180.00
          |                                        |
 310      |                                        | TESTN2
--------->|         6377.7     LBMOL/HR            |--------->
  -312.60 |                                        |  -180.00
          |                                        |
 309      |                                        | TESTWAST
--------->|         4500.0     LBMOL/HR            |--------->
  -308.23 |                                        |  -180.00
          |                                        |
 305      |                                        | TESTFEED
<---------|         10582.     LBMOL/HR            |<---------
  -276.56 |                                        |  -162.76
          |                                        |
          ------------------------------------------


BLOCK:  HPC      MODEL: RADFRAC
-------------------------------
   INLETS   - 305      STAGE  14
   OUTLETS  - 306      STAGE   1
              307      STAGE  14
              HEAT     STAGE   1
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           10582.2         10582.2         0.00000
      MASS(LB/HR    )          305300.         305300.         0.366252E-12
      ENTHALPY(BTU/HR  )     -0.369355E+08   -0.369377E+08    0.600630E-04

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

```
                    *********************
                    ****  INPUT DATA  ****
                    *********************

 ****   INPUT PARAMETERS   ****

  NUMBER OF STAGES                                            14
  ALGORITHM OPTION                                          STANDARD
  ABSORBER OPTION                                           NO
  INITIALIZATION OPTION                                     STANDARD
  HYDRAULIC PARAMETER CALCULATIONS                          NO
  INSIDE LOOP CONVERGENCE METHOD                            BROYDEN
  DESIGN SPECIFICATION METHOD                               NESTED
  MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                      25
  MAXIMUM NO. OF INSIDE LOOP ITERATIONS                       10
  MAXIMUM NUMBER OF FLASH ITERATIONS                          30
  FLASH TOLERANCE                                              0.000100000
  OUTSIDE LOOP CONVERGENCE TOLERANCE                           0.000100000

 ****   COL-SPECS   ****

  MOLAR VAPOR DIST / TOTAL DIST                                0.0
  MOLAR REFLUX RATIO                                           1.25000
  REBOILER DUTY                  BTU/HR                        0.0

 ****    PROFILES   ****

  P-SPEC          STAGE   1  PRES, PSIA                      92.0000

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


 ***   COMPONENT SPLIT FRACTIONS   ***

                          OUTLET STREAMS
                          --------------
              306           307
  COMPONENT:
  OXYGEN      .94495E-02   .99055
  NITROGEN    .35111       .64889


 ***    SUMMARY OF KEY RESULTS    ***

  TOP STAGE TEMPERATURE          F                        -284.520
  BOTTOM STAGE TEMPERATURE       F                        -278.983
  TOP STAGE LIQUID FLOW          LBMOL/HR                3,695.31
  BOTTOM STAGE LIQUID FLOW       LBMOL/HR                7,625.94
  TOP STAGE VAPOR FLOW           LBMOL/HR                    0.0
  BOILUP VAPOR FLOW              LBMOL/HR                6,355.77
  MOLAR REFLUX RATIO                                         1.25000
  CONDENSER DUTY (W/O SUBCOOL)   BTU/HR                     -0.135317+08
  REBOILER DUTY                  BTU/HR                      0.0
```

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

 DEW POINT                         0.20979E-04  STAGE= 12
 BUBBLE POINT                      0.66444E-05  STAGE= 12
 COMPONENT MASS BALANCE            0.43573E-06  STAGE=  7 COMP=OXYGEN
 ENERGY BALANCE                    0.11648E-04  STAGE= 14


****    PROFILES   ****

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

                                             ENTHALPY
STAGE TEMPERATURE   PRESSURE              BTU/LBMOL           HEAT DUTY
      F             PSIA           LIQUID       VAPOR          BTU/HR

  1  -284.52        92.000       -4690.2      -2657.1      -.13532+08
  2  -284.34        92.100       -4693.6      -2655.8
  3  -284.12        92.200       -4698.0      -2654.2
 12  -279.99        93.100       -4781.7      -2622.9
 13  -279.46        93.200       -4791.4      -2618.9
 14  -278.98        93.300       -4799.9      -2615.3

STAGE     FLOW RATE                  FEED RATE                PRODUCT RATE
           LBMOL/HR                  LBMOL/HR                   LBMOL/HR
      LIQUID     VAPOR       LIQUID     VAPOR    MIXED      LIQUID    VAPOR
  1  6652.      0.000                                       2956.2440
  2  3684.      6652.
  3  3670.      6640.
 12  3426.      6411.
 13  3400.      6382.
 14  7626.      6356.                          .10582+05  7625.9445

  ****  MASS FLOW PROFILES  ****

STAGE     FLOW RATE                  FEED RATE                PRODUCT RATE
           LB/HR                     LB/HR                      LB/HR
      LIQUID     VAPOR       LIQUID     VAPOR    MIXED      LIQUID    VAPOR
  1 0.1865E+06  0.000                                       .82898+05
  2 0.1034E+06 0.1865E+06
  3 0.1032E+06 0.1863E+06
 12 0.9925E+05 0.1826E+06
 13 0.9884E+05 0.1821E+06
 14 0.2224E+06 0.1817E+06                      .30530+06  .22240+06

                      ****   MOLE-X-PROFILE     ****
  STAGE     OXYGEN       NITROGEN
     1    0.71034E-02   0.99290
     2    0.16215E-01   0.98379
     3    0.27606E-01   0.97239
    12    0.24065       0.75935
    13    0.26609       0.73391
    14    0.28865       0.71135

                      ****   MOLE-Y-PROFILE     ****
  STAGE     OXYGEN       NITROGEN
     1    0.30987E-02   0.99690
     2    0.71034E-02   0.99290
```

```
      3    0.12158E-01   0.98784
     12    0.11809       0.88191
     13    0.13246       0.86754
     14    0.14563       0.85437

                         ****   K-VALUES           ****
   STAGE     OXYGEN        NITROGEN
      1    0.43622        1.0040
      2    0.43808        1.0093
      3    0.44040        1.0159
     12    0.49063        1.1614
     13    0.49783        1.1821
     14    0.50451        1.2011

                         ****   MASS-X-PROFILE     ****
   STAGE     OXYGEN        NITROGEN
      1    0.81058E-02   0.99189
      2    0.18479E-01   0.98152
      3    0.31410E-01   0.96859
     12    0.26578       0.73422
     13    0.29286       0.70714
     14    0.31671       0.68329

                         ****   MASS-Y-PROFILE     ****
   STAGE     OXYGEN        NITROGEN
      1    0.35380E-02   0.99646
      2    0.81058E-02   0.99189
      3    0.13864E-01   0.98614
     12    0.13266       0.86734
     13    0.14851       0.85149
     14    0.16297       0.83703



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


        *** DEFINITIONS ***

         MARANGONI INDEX = SIGMA - SIGMATO
         FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
         QR = QV*SQRT(RHOV/(RHOL-RHOV))
         F FACTOR = QV*SQRT(RHOV)
           WHERE:
           SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
           SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
           ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
           MV IS THE MASS FLOW OF VAPOR TO THE STAGE
           RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
           RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
           QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE


                     TEMPERATURE
                         F
 STAGE       LIQUID FROM       VAPOR TO
```

1	-284.52	-284.34
2	-284.34	-284.12
3	-284.12	-283.85
12	-279.99	-279.46
13	-279.46	-278.98
14	-278.98	-399.60

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	0.18652E+06	0.18652E+06	4221.9	0.11434E+06	28.042	28.042
2	0.10344E+06	0.18633E+06	2333.4	0.11420E+06	28.078	28.062
3	0.10320E+06	0.18610E+06	2318.4	0.11406E+06	28.123	28.087
12	99250.	0.18215E+06	2058.1	0.11245E+06	28.973	28.541
13	98837.	0.18174E+06	2030.0	0.11226E+06	29.074	28.594
14	0.22240E+06	0.30530E+06	4529.4	0.19018E+06	29.164	28.850

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	44.180	1.6313	0.78193E-01	0.71660E-02	23.849
2	44.328	1.6316	0.78466E-01	0.71769E-02	23.825
3	44.515	1.6316	0.78819E-01	0.71901E-02	23.796
12	48.224	1.6198	0.86314E-01	0.74113E-02	23.259
13	48.688	1.6189	0.87278E-01	0.74362E-02	23.193
14	49.102	1.6053	0.88140E-01	0.24004E-02	23.135

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.19215	22388.	0.14604E+06
2	-.23927E-01	0.10650	22325.	0.14588E+06
3	-.29393E-01	0.10617	22249.	0.14570E+06
12	-.70284E-01	0.99864E-01	20964.	0.14312E+06
13	-.65403E-01	0.99170E-01	20819.	0.14283E+06
14	-.58659E-01	0.13172	34964.	0.24096E+06

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

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

STARTING STAGE NUMBER                                  2
ENDING STAGE NUMBER                                   14
FLOODING CALCULATION METHOD                      GLITSCH6

DESIGN PARAMETERS
-----------------
PEAK CAPACITY FACTOR                             1.00000
SYSTEM FOAMING FACTOR                            1.00000
```

FLOODING FACTOR		0.80000
MINIMUM COLUMN DIAMETER	FT	1.00000
MINIMUM DC AREA/COLUMN AREA		0.100000
HOLE AREA/ACTIVE AREA		0.100000

TRAY SPECIFICATIONS

TRAY TYPE		SIEVE
NUMBER OF PASSES		4
TRAY SPACING	FT	0.75000

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

STAGE WITH MAXIMUM DIAMETER		14
COLUMN DIAMETER	FT	9.87219
DC AREA/COLUMN AREA		0.093750
SIDE DOWNCOMER VELOCITY	FT/SEC	0.17533
FLOW PATH LENGTH	FT	1.85257
SIDE DOWNCOMER WIDTH	FT	0.60053
SIDE WEIR LENGTH	FT	4.71928
CENTER DOWNCOMER WIDTH	FT	0.38778
CENTER WEIR LENGTH	FT	9.86457
OFF-CENTER DOWNCOMER WIDTH	FT	0.43654
OFF-CENTER SHORT WEIR LENGTH	FT	8.53224
OFF-CENTER LONG WEIR LENGTH	FT	8.98378
TRAY CENTER TO OCDC CENTER	FT	2.26473

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA PER PANEL	SIDE DC AREA PER PANEL
	FT	SQFT	SQFT	SQFT
2	9.8722	76.545	15.309	1.7940
3	9.8722	76.545	15.309	1.7940
4	9.8722	76.545	15.309	1.7940
5	9.8722	76.545	15.309	1.7940
6	9.8722	76.545	15.309	1.7940
7	9.8722	76.545	15.309	1.7940
8	9.8722	76.545	15.309	1.7940
9	9.8722	76.545	15.309	1.7940
10	9.8722	76.545	15.309	1.7940
11	9.8722	76.545	15.309	1.7940
12	9.8722	76.545	15.309	1.7940
13	9.8722	76.545	15.309	1.7940
14	9.8722	76.545	15.309	1.7940

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP	DC BACKUP	DC BACKUP/ (TSPC+WHT)
		PSI	FT	
2	50.22	0.3997E-01	0.2822	34.73
3	50.04	0.4002E-01	0.2815	34.64
4	49.82	0.4009E-01	0.2806	34.53
5	49.55	0.4016E-01	0.2795	34.40
6	49.25	0.4026E-01	0.2783	34.25

```
  7     48.90      0.4037E-01  0.2769       34.07
  8     48.53      0.4049E-01  0.2753       33.89
  9     48.12      0.4063E-01  0.2738       33.69
 10     47.71      0.4078E-01  0.2722       33.50
 11     47.31      0.4093E-01  0.2706       33.31
 12     46.93      0.4108E-01  0.2692       33.13
 13     46.59      0.4122E-01  0.2679       32.97
 14     80.00      0.5721E-01  0.3927       48.33

      HEIGHT      DC REL      TR LIQ REL  FRA APPR TO
STAGE OVER WEIR   FROTH DENS  FROTH DENS  SYS LIMIT
        FT
  2     0.6175E-01  0.6048      0.3950       16.30
  3     0.6145E-01  0.6049      0.3953       16.27
  4     0.6109E-01  0.6051      0.3956       16.22
  5     0.6065E-01  0.6053      0.3960       16.17
  6     0.6015E-01  0.6055      0.3964       16.11
  7     0.5957E-01  0.6057      0.3969       16.04
  8     0.5895E-01  0.6060      0.3974       15.96
  9     0.5828E-01  0.6062      0.3980       15.88
 10     0.5761E-01  0.6064      0.3985       15.80
 11     0.5696E-01  0.6066      0.3990       15.72
 12     0.5634E-01  0.6068      0.3995       15.65
 13     0.5579E-01  0.6070      0.4000       15.58
 14     0.1209      0.6071      0.2808       26.29

BLOCK:  LPC      MODEL: RADFRAC
-------------------------------
   INLETS    - 307      STAGE  12
               304      STAGE  18
               306      STAGE   1
               HEAT     STAGE  38
   OUTLETS   - 310      STAGE   1
               308      STAGE  38
               309      STAGE   8
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            13227.7         13227.7        0.137513E-15
      MASS(LB/HR    )           381625.         381625.        0.258762E-08
      ENTHALPY(BTU/HR  )      -0.429223E+08   -0.424392E+08   -0.112548E-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  ****
                        **********************

  ****   INPUT PARAMETERS   ****
```

```
 NUMBER OF STAGES                                                   38
 ALGORITHM OPTION                                                 STANDARD
 ABSORBER OPTION                                                  NO
 INITIALIZATION OPTION                                            STANDARD
 HYDRAULIC PARAMETER CALCULATIONS                                 NO
 INSIDE LOOP CONVERGENCE METHOD                                   BROYDEN
 DESIGN SPECIFICATION METHOD                                      NESTED
 MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                             25
 MAXIMUM NO. OF INSIDE LOOP ITERATIONS                              10
 MAXIMUM NUMBER OF FLASH ITERATIONS                                 30
 FLASH TOLERANCE                                                     0.000100000
 OUTSIDE LOOP CONVERGENCE TOLERANCE                                  0.000100000

****   COL-SPECS   ****

 MOLAR VAPOR DIST / TOTAL DIST                                       1.00000
 MOLAR BOTTOMS RATE                LBMOL/HR                      2,350.00
 CONDENSER DUTY (W/O SUBCOOL)      BTU/HR                            0.0

****    PROFILES   ****

 P-SPEC          STAGE   1  PRES, PSIA                             23.0000

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


***   COMPONENT SPLIT FRACTIONS   ***

                         OUTLET STREAMS
                         --------------
              310          308          309
 COMPONENT:
 OXYGEN      .20054E-01   .80091       .17904
 NITROGEN    .60498       .11982E-01   .38303


***    SUMMARY OF KEY RESULTS    ***

 TOP STAGE TEMPERATURE             F                              -312.602
 BOTTOM STAGE TEMPERATURE          F                              -288.739
 TOP STAGE LIQUID FLOW             LBMOL/HR                      2,426.07
 BOTTOM STAGE LIQUID FLOW          LBMOL/HR                      2,350.00
 TOP STAGE VAPOR FLOW              LBMOL/HR                      6,377.74
 BOILUP VAPOR FLOW                 LBMOL/HR                      5,033.14
 MOLAR BOILUP RATIO                                                  2.14176
 CONDENSER DUTY (W/O SUBCOOL)      BTU/HR                            0.0
 REBOILER DUTY                     BTU/HR                            0.140149+08

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

 DEW POINT                          0.33563E-04  STAGE= 34
 BUBBLE POINT                       0.16473E-04  STAGE= 29
 COMPONENT MASS BALANCE             0.22176E-05  STAGE= 36 COMP=NITROGEN
 ENERGY BALANCE                     0.54292E-05  STAGE= 36


****    PROFILES   ****
```

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

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	-312.60	23.000	-5107.9	-2750.0	
2	-312.24	23.000	-5120.0	-2747.3	
7	-308.88	23.600	-5201.2	-2724.2	
8	-308.23	23.720	-5214.7	-2719.8	
9	-307.88	23.840	-5220.2	-2717.5	
10	-307.68	23.960	-5221.8	-2716.3	
11	-307.55	24.080	-5221.7	-2715.5	
12	-307.44	24.200	-5220.9	-2715.0	
13	-307.31	24.320	-5220.8	-2714.2	
16	-306.50	24.680	-5230.4	-2709.0	
17	-305.89	24.800	-5241.4	-2704.9	
18	-305.80	24.920	-5240.2	-2704.4	
37	-291.89	27.200	-5376.9	-2609.2	
38	-288.74	27.320	-5387.8	-2587.2	.14015+08

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	2426.	6378.	2441.2205	515.0234			6377.7357
2	2404.	5848.					
7	2270.	5717.					
8	2248.	0.1019E+05					4500.0000
9	2238.	0.1017E+05					
10	2234.	0.1016E+05					
11	2232.	0.1016E+05					
12	8575.	0.1015E+05	6346.6577	1279.2868			
13	8571.	8870.					
16	8509.	8839.					
17	8010.	8805.		2645.5471			
18	8013.	5660.					
37	7383.	5149.					
38	2350.	5033.				2350.0000	

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR LIQUID	FLOW RATE LB/HR VAPOR	FEED RATE LB/HR LIQUID	FEED RATE LB/HR VAPOR	FEED RATE LB/HR MIXED	PRODUCT RATE LB/HR LIQUID	PRODUCT RATE LB/HR VAPOR
1	0.6824E+05	0.1789E+06	.68466+05	.14433+05			.17888+06
2	0.6790E+05	0.1642E+06					
7	0.6596E+05	0.1623E+06					
8	0.6564E+05	0.2900E+06					.12804+06
9	0.6550E+05	0.2897E+06					
10	0.6543E+05	0.2895E+06					
11	0.6539E+05	0.2895E+06					
12	0.2513E+06	0.2894E+06	.18594+06	.36462+05			
13	0.2513E+06	0.2529E+06					
16	0.2506E+06	0.2526E+06					
17	0.2368E+06	0.2522E+06		.76325+05			
18	0.2369E+06	0.1621E+06					
37	0.2325E+06	0.1579E+06					

```
 38 0.7470E+05 0.1578E+06                                   .74698+05

                       ****   MOLE-X-PROFILE      ****
  STAGE     OXYGEN        NITROGEN
     1     0.28310E-01   0.97169
     2     0.56382E-01   0.94362
     7     0.26182       0.73818
     8     0.29746       0.70254
     9     0.31349       0.68651
    10     0.32032       0.67968
    11     0.32301       0.67699
    12     0.32388       0.67612
    13     0.32673       0.67327
    16     0.35893       0.64107
    17     0.38904       0.61096
    18     0.38910       0.61090
    37     0.87253       0.12747
    38     0.94672       0.53283E-01

                       ****   MOLE-Y-PROFILE      ****
  STAGE     OXYGEN        NITROGEN
     1     0.87347E-02   0.99127
     2     0.17681E-01   0.98232
     7     0.94579E-01   0.90542
     8     0.11052       0.88948
     9     0.11807       0.88193
    10     0.12143       0.87857
    11     0.12285       0.87715
    12     0.12340       0.87660
    13     0.12490       0.87510
    16     0.14132       0.85868
    17     0.15731       0.84269
    18     0.15750       0.84250
    37     0.66456       0.33544
    38     0.83790       0.16210

                       ****   K-VALUES            ****
  STAGE     OXYGEN        NITROGEN
     1     0.30853        1.0201
     2     0.31359        1.0410
     7     0.36124        1.2265
     8     0.37154        1.2661
     9     0.37665        1.2846
    10     0.37910        1.2926
    11     0.38033        1.2957
    12     0.38101        1.2965
    13     0.38228        1.2998
    16     0.39372        1.3395
    17     0.40434        1.3793
    18     0.40477        1.3791
    37     0.76164        2.6317
    38     0.88505        3.0424

                       ****   MASS-X-PROFILE      ****
  STAGE     OXYGEN        NITROGEN
     1     0.32208E-01   0.96779
     2     0.63891E-01   0.93611
     7     0.28833       0.71167
     8     0.32598       0.67402
```

```
     9    0.34280       0.65720
    10    0.34994       0.65006
    11    0.35275       0.64725
    12    0.35366       0.64634
    13    0.35663       0.64337
    16    0.39008       0.60992
    17    0.42108       0.57892
    18    0.42114       0.57886
    37    0.88661       0.11339
    38    0.95304       0.46958E-01

                        ****   MASS-Y-PROFILE     ****
  STAGE     OXYGEN        NITROGEN
     1    0.99650E-02   0.99004
     2    0.20146E-01   0.97985
     7    0.10660       0.89340
     8    0.12429       0.87571
     9    0.13264       0.86736
    10    0.13635       0.86365
    11    0.13792       0.86208
    12    0.13852       0.86148
    13    0.14018       0.85982
    16    0.15824       0.84176
    17    0.17575       0.82425
    18    0.17596       0.82404
    37    0.69353       0.30647
    38    0.85516       0.14484




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


       *** DEFINITIONS ***

        MARANGONI INDEX = SIGMA - SIGMATO
        FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
        QR = QV*SQRT(RHOV/(RHOL-RHOV))
        F FACTOR = QV*SQRT(RHOV)
          WHERE:
          SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
          SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
          ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
          MV IS THE MASS FLOW OF VAPOR TO THE STAGE
          RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
          RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
          QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE


                    TEMPERATURE
                        F
STAGE        LIQUID FROM       VAPOR TO
   1         -312.60           -312.24
   2         -312.24           -311.68
   7         -308.88           -308.23
   8         -308.23           -307.88
```

9	-307.88	-307.68
10	-307.68	-307.55
11	-307.55	-307.44
12	-307.44	-307.35
13	-307.31	-307.13
16	-306.50	-305.89
17	-305.89	-286.49
18	-305.80	-305.71
37	-291.89	-288.74
38	-288.74	-288.74

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	68236.	0.16422E+06	1376.9	0.37942E+06	28.126	28.084
2	67898.	0.16388E+06	1356.2	0.37753E+06	28.238	28.130
7	65955.	0.16194E+06	1224.5	0.36841E+06	29.057	28.454
8	65644.	0.28967E+06	1203.4	0.65648E+06	29.199	28.484
9	65499.	0.28953E+06	1194.1	0.65335E+06	29.263	28.497
10	65429.	0.28946E+06	1190.2	0.65026E+06	29.290	28.503
11	65391.	0.28942E+06	1188.6	0.64721E+06	29.301	28.505
12	0.25127E+06	0.28936E+06	4567.3	0.64741E+06	29.304	28.510
13	0.25126E+06	0.25289E+06	4563.7	0.56061E+06	29.316	28.522
16	0.25055E+06	0.25218E+06	4501.4	0.55317E+06	29.444	28.640
17	0.23681E+06	0.23843E+06	4209.4	0.59685E+06	29.564	28.708
18	0.23689E+06	0.16219E+06	4211.8	0.35260E+06	29.564	28.642
37	0.23250E+06	0.15780E+06	3499.0	0.32104E+06	31.491	31.353
38	74698.	0.0000	1097.1	0.0000	31.786	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	49.557	0.43283	0.13638	0.58238E-02	26.153
2	50.064	0.43409	0.13772	0.58496E-02	26.090
7	53.863	0.43957	0.14649	0.60151E-02	25.584
8	54.550	0.44125	0.14798	0.60319E-02	25.493
9	54.853	0.44315	0.14852	0.60415E-02	25.448
10	54.974	0.44514	0.14861	0.60477E-02	25.424
11	55.013	0.44718	0.14849	0.60525E-02	25.411
12	55.016	0.44696	0.14829	0.60564E-02	25.401
13	55.058	0.45110	0.14819	0.60672E-02	25.387
16	55.661	0.45588	0.14903	0.61281E-02	25.288
17	56.257	0.39949	0.15025	0.68859E-02	25.208
18	56.243	0.45997	0.15002	0.61363E-02	25.200
37	66.448	0.49153	0.16612	0.71307E-02	23.644
38	68.087		0.16789		23.338

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.38832E-01	35614.	0.24962E+06
2	-.62909E-01	0.38579E-01	35308.	0.24874E+06
7	-.10344	0.36792E-01	33418.	0.24426E+06
8	-.91072E-01	0.20381E-01	59284.	0.43608E+06
9	-.45348E-01	0.20334E-01	58963.	0.43493E+06
10	-.23600E-01	0.20340E-01	58752.	0.43385E+06
11	-.13762E-01	0.20370E-01	58590.	0.43280E+06

```
 12   -.55294E-02      0.78270E-01       58592.          0.43282E+06
 13   -.14097E-01      0.89934E-01       50954.          0.37653E+06
 16   -.49021E-01      0.89917E-01       50269.          0.37350E+06
 17   -.80429E-01      0.83693E-01       50475.          0.37724E+06
 18   -.73392E-02      0.13208           32018.          0.23914E+06
 37   -.42462          0.12672           27715.          0.22508E+06
 38   -.30567                            0.0000           0.0000



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


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

  STARTING STAGE NUMBER                                         1
  ENDING STAGE NUMBER                                          37
  FLOODING CALCULATION METHOD                             GLITSCH6

  DESIGN PARAMETERS
  -----------------
  PEAK CAPACITY FACTOR                                    1.00000
  SYSTEM FOAMING FACTOR                                   1.00000
  FLOODING FACTOR                                         0.80000
  MINIMUM COLUMN DIAMETER          FT                     1.00000
  MINIMUM DC AREA/COLUMN AREA                             0.100000
  HOLE AREA/ACTIVE AREA                                   0.100000

  TRAY SPECIFICATIONS
  -------------------
  TRAY TYPE                                               SIEVE
  NUMBER OF PASSES                                            1
  TRAY SPACING                     FT                     1.00000


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

  STAGE WITH MAXIMUM DIAMETER                                  12
  COLUMN DIAMETER                  FT                    11.3722
  DC AREA/COLUMN AREA                                     0.100000
  DOWNCOMER VELOCITY               FT/SEC                 0.12491
  FLOW PATH LENGTH                 FT                     7.81325
  SIDE DOWNCOMER WIDTH             FT                     1.77947
  SIDE WEIR LENGTH                 FT                     8.26316
  CENTER DOWNCOMER WIDTH           FT                     0.0
  CENTER WEIR LENGTH               FT                     MISSING
  OFF-CENTER DOWNCOMER WIDTH       FT                     0.0
  OFF-CENTER SHORT WEIR LENGTH     FT                     MISSING
  OFF-CENTER LONG WEIR LENGTH      FT                     MISSING
  TRAY CENTER TO OCDC CENTER       FT                     0.0


                         **** SIZING PROFILES ****
```

STAGE	DIAMETER FT	TOTAL AREA SQFT	ACTIVE AREA SQFT	SIDE DC AREA SQFT
1	11.372	101.57	81.258	10.157
2	11.372	101.57	81.258	10.157
3	11.372	101.57	81.258	10.157
4	11.372	101.57	81.258	10.157
5	11.372	101.57	81.258	10.157
6	11.372	101.57	81.258	10.157
7	11.372	101.57	81.258	10.157
8	11.372	101.57	81.258	10.157
9	11.372	101.57	81.258	10.157
10	11.372	101.57	81.258	10.157
11	11.372	101.57	81.258	10.157
12	11.372	101.57	81.258	10.157
13	11.372	101.57	81.258	10.157
14	11.372	101.57	81.258	10.157
15	11.372	101.57	81.258	10.157
16	11.372	101.57	81.258	10.157
17	11.372	101.57	81.258	10.157
18	11.372	101.57	81.258	10.157
19	11.372	101.57	81.258	10.157
20	11.372	101.57	81.258	10.157
21	11.372	101.57	81.258	10.157
22	11.372	101.57	81.258	10.157
23	11.372	101.57	81.258	10.157
24	11.372	101.57	81.258	10.157
25	11.372	101.57	81.258	10.157
26	11.372	101.57	81.258	10.157
27	11.372	101.57	81.258	10.157
28	11.372	101.57	81.258	10.157
29	11.372	101.57	81.258	10.157
30	11.372	101.57	81.258	10.157
31	11.372	101.57	81.258	10.157
32	11.372	101.57	81.258	10.157
33	11.372	101.57	81.258	10.157
34	11.372	101.57	81.258	10.157
35	11.372	101.57	81.258	10.157
36	11.372	101.57	81.258	10.157
37	11.372	101.57	81.258	10.157

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
1	43.67	0.5039E-01	0.4619	42.64
2	43.27	0.5056E-01	0.4571	42.20
3	42.81	0.5079E-01	0.4517	41.69
4	42.30	0.5106E-01	0.4456	41.13
5	41.77	0.5138E-01	0.4393	40.55
6	41.24	0.5171E-01	0.4332	39.99
7	40.75	0.5203E-01	0.4279	39.49
8	68.87	0.7522E-01	0.4901	45.24
9	68.49	0.7514E-01	0.4869	44.94
10	68.25	0.7502E-01	0.4852	44.78
11	68.07	0.7486E-01	0.4842	44.69
12	80.00	0.9105E-01	1.672	154.3
13	71.67	0.8307E-01	1.646	152.0

14	71.46	0.8302E-01	1.641	151.5
15	71.17	0.8299E-01	1.631	150.5
16	70.71	0.8302E-01	1.612	148.8
17	69.81	0.8241E-01	1.464	135.2
18	49.79	0.7051E-01	1.445	133.4
19	49.74	0.7050E-01	1.446	133.5
20	49.70	0.7049E-01	1.448	133.6
21	49.66	0.7048E-01	1.449	133.7
22	49.61	0.7047E-01	1.450	133.9
23	49.57	0.7046E-01	1.451	134.0
24	49.53	0.7046E-01	1.453	134.1
25	49.49	0.7045E-01	1.454	134.2
26	49.44	0.7044E-01	1.455	134.3
27	49.40	0.7043E-01	1.456	134.4
28	49.35	0.7043E-01	1.457	134.5
29	49.29	0.7043E-01	1.457	134.5
30	49.21	0.7045E-01	1.456	134.4
31	49.08	0.7050E-01	1.451	134.0
32	48.81	0.7062E-01	1.439	132.9
33	48.28	0.7092E-01	1.412	130.3
34	47.26	0.7159E-01	1.357	125.2
35	45.65	0.7285E-01	1.272	117.4
36	43.87	0.7461E-01	1.182	109.1
37	42.61	0.7629E-01	1.118	103.2

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
1	0.1221	0.6075	0.3350	18.54
2	0.1206	0.6076	0.3358	18.44
3	0.1190	0.6076	0.3366	18.32
4	0.1171	0.6077	0.3375	18.20
5	0.1152	0.6078	0.3383	18.07
6	0.1133	0.6079	0.3392	17.95
7	0.1116	0.6080	0.3400	17.83
8	0.1463	0.6080	0.2245	31.74
9	0.1454	0.6081	0.2249	31.63
10	0.1449	0.6081	0.2253	31.54
11	0.1446	0.6081	0.2257	31.47
12	0.3711	0.6081	0.2257	31.55
13	0.3453	0.6081	0.2491	27.46
14	0.3444	0.6081	0.2496	27.39
15	0.3430	0.6081	0.2500	27.30
16	0.3405	0.6081	0.2506	27.19
17	0.3262	0.6081	0.2488	27.28
18	0.2588	0.6081	0.3449	17.37
19	0.2587	0.6081	0.3453	17.35
20	0.2586	0.6081	0.3457	17.32
21	0.2585	0.6081	0.3461	17.30
22	0.2584	0.6081	0.3465	17.27
23	0.2583	0.6081	0.3469	17.25
24	0.2582	0.6081	0.3473	17.22
25	0.2581	0.6081	0.3477	17.20
26	0.2580	0.6081	0.3481	17.18
27	0.2579	0.6081	0.3485	17.15
28	0.2578	0.6081	0.3489	17.13
29	0.2576	0.6081	0.3493	17.10
30	0.2572	0.6081	0.3497	17.07
31	0.2566	0.6081	0.3502	17.03

```
 32    0.2552      0.6081      0.3509       16.97
 33    0.2523      0.6082      0.3520       16.85
 34    0.2465      0.6082      0.3537       16.65
 35    0.2376      0.6082      0.3561       16.35
 36    0.2279      0.6083      0.3582       16.05
 37    0.2210      0.6083      0.3591       15.88

BLOCK:  MAC      MODEL: MCOMPR
------------------------------
  INLET STREAMS:    301          TO STAGE   1
  OUTLET STREAMS:   302        FROM STAGE   3
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           13227.7         13227.7         0.00000
      MASS(LB/HR   )           381625.         381625.         0.00000
      ENTHALPY(BTU/HR  )       692448.        0.136150E+07   -0.491410

                     ***  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
  NUMBER OF STAGES                                             3
  FINAL PRESSURE, PSIA                                       105.000
  DISTRIBUTION AMONG STAGES                                    EQUAL P-RATIO

                   COMPRESSOR SPECIFICATIONS PER STAGE

  STAGE                      MECHANICAL      ISENTROPIC
  NUMBER                     EFFICIENCY      EFFICIENCY


    1                         1.000          0.7200
    2                         1.000          0.7200
    3                         1.000          0.7200

                   COOLER SPECIFICATIONS PER STAGE

  STAGE      PRESSURE DROP      TEMPERATURE
  NUMBER     PSI                F

    1        3.000              95.00
    2        3.000              95.00
    3        3.000              95.00

                          ***  RESULTS  ***

  FINAL PRESSURE, PSIA                                       102.000
  TOTAL WORK REQUIRED, HP                                 18,717.9
  TOTAL COOLING DUTY , BTU/HR                                 -0.469573+08
```

```
                         ***  PROFILE  ***

                         COMPRESSOR PROFILE

  STAGE      OUTLET       PRESSURE     OUTLET
  NUMBER     PRESSURE     RATIO        TEMPERATURE
             PSIA                      F

    1        28.31        1.926        239.8
    2        54.52        2.154        282.4
    3        105.0        2.038        267.6

  STAGE      INDICATED     BRAKE
  NUMBER     HORSEPOWER    HORSEPOWER
             HP            HP
    1        5625.         5625.
    2        6819.         6819.
    3        6273.         6273.

  STAGE      HEAD          VOLUMETRIC    ISENTROPIC
  NUMBER     DEVELOPED     FLOW          EFFICIENCY
             FT-LBF/LB     CUFT/HR
    1       0.2101E+05    0.5257E+07     0.7200
    2       0.2547E+05    0.3109E+07     0.7200
    3       0.2344E+05    0.1526E+07     0.7200

                         COOLER PROFILE

  STAGE      OUTLET        OUTLET       COOLING     VAPOR
  NUMBER     TEMPERATURE   PRESSURE     LOAD        FRACTION
             F             PSIA         BTU/HR

    1         95.00         25.31       -.1342E+08   1.000
    2         95.00         51.52       -.1743E+08   1.000
    3         95.00         102.0       -.1611E+08   1.000

BLOCK:  SPLITTER MODEL: FSPLIT
------------------------------
  INLET STREAM:           302
  OUTLET STREAMS:         TESTHPC     TESTLPC
  PROPERTY OPTION SET:    PENG-ROB  STANDARD PR EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            13227.7         13227.7         0.00000
      MASS(LB/HR   )            381625.         381625.         0.00000
      ENTHALPY(BTU/HR  )       0.136150E+07    0.136150E+07   -0.171010E-15

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

                        ***  INPUT DATA  ***

 FRACTION OF FLOW                  STRM=TESTHPC  FRAC=         0.80000
```

```
                    ***  RESULTS  ***

 STREAM= TESTHPC       SPLIT=         0.80000     KEY=  0    STREAM-ORDER=   1
         TESTLPC                      0.20000           0                    2

BLOCK:  TURBINE  MODEL: COMPR
-----------------------------
  INLET STREAM:          303
  OUTLET STREAM:         304
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

               ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)         2645.55         2645.55         0.00000
      MASS(LB/HR   )         76325.1         76325.1         0.00000
      ENTHALPY(BTU/HR  )   -0.434660E+07   -0.598459E+07    0.273701

               ***  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 TURBINE
   OUTLET PRESSURE  PSIA                               24.9831
   ISENTROPIC EFFICIENCY                                0.90000
   MECHANICAL EFFICIENCY                                1.00000

                    ***  RESULTS  ***

   INDICATED  HORSEPOWER REQUIREMENT  HP              -643.754
   BRAKE      HORSEPOWER REQUIREMENT  HP              -643.754
   NET WORK REQUIRED                  HP              -643.754
   POWER LOSSES                       HP                 0.0
   ISENTROPIC HORSEPOWER REQUIREMENT  HP              -715.282
   CALCULATED OUTLET TEMP  F                          -244.445
   ISENTROPIC TEMPERATURE  F                          -254.083
   EFFICIENCY (POLYTR/ISENTR) USED                      0.90000
   OUTLET VAPOR FRACTION                                1.00000
   HEAD DEVELOPED,       FT-LBF/LB                 -18,555.6
   MECHANICAL EFFICIENCY USED                           1.00000
   INLET HEAT CAPACITY RATIO                            1.45678
   INLET VOLUMETRIC FLOW RATE , CUFT/HR            83,304.3
   OUTLET VOLUMETRIC FLOW RATE, CUFT/HR           238,883.
   INLET  COMPRESSIBILITY FACTOR                        0.96649
   OUTLET COMPRESSIBILITY FACTOR                        0.97671
   AV. ISENT. VOL. EXPONENT                             1.40045
   AV. ISENT. TEMP EXPONENT                             1.41082
   AV. ACTUAL VOL. EXPONENT                             1.33537
   AV. ACTUAL TEMP EXPONENT                             1.34884
```

Stream Report

```
HEAT
----

STREAM ID                HEAT
FROM :                   HPC
TO   :                   LPC
CLASS:                   HEAT

STREAM ATTRIBUTES:
HEAT
Q        BTU/HR         1.3532+07
TBEG     F             -284.3381
TEND     F             -284.5198

301 302 303 304 305
-------------------

STREAM ID                301         302         303         304         305
FROM :                   ----        MAC         MHX1        TURBINE     MHX2
TO   :                   MAC         SPLITTER    TURBINE     LPC         HPC


CONV. MAX. REL. ERR:      0.0         0.0         0.0         0.0     6.4629-05
SUBSTREAM: MIXED
PHASE:                   VAPOR       VAPOR       VAPOR       VAPOR       MIXED
COMPONENTS: LBMOL/HR
  OXYGEN               2777.8245   2777.8245    555.5649    555.5649   2222.2596
  NITROGEN             1.0450+04   1.0450+04   2089.9822   2089.9822   8359.9290
  METHANE                 0.0         0.0         0.0         0.0         0.0
  CO2                     0.0         0.0         0.0         0.0         0.0
  WATER                   0.0         0.0         0.0         0.0         0.0
TOTAL FLOW:
  LBMOL/HR             1.3228+04   1.3228+04   2645.5471   2645.5471   1.0582+04
  LB/HR                3.8163+05   3.8163+05   7.6325+04   7.6325+04   3.0530+05
  CUFT/HR              5.2571+06   7.6968+05   8.3304+04   2.3888+05   1.0397+05
STATE VARIABLES:
  TEMP   F               85.0000     95.0000   -150.0000   -244.4446   -276.5624
  PRES   PSIA            14.7000    102.0000    102.0000     24.9831    102.0000
  VFRAC                   1.0000      1.0000      1.0000      1.0000      0.5920
  LFRAC                   0.0         0.0         0.0         0.0         0.4080
  SFRAC                   0.0         0.0         0.0         0.0         0.0
ENTHALPY:
  BTU/LBMOL              52.3482    102.9280  -1642.9873  -2262.1364  -3490.3427
  BTU/LB                  1.8145      3.5676    -56.9485    -78.4092   -120.9807
  BTU/HR               6.9245+05   1.3615+06  -4.3466+06  -5.9846+06  -3.6935+07
ENTROPY:
  BTU/LBMOL-R             1.1179     -2.6315     -6.7913     -6.4642    -15.6134
  BTU/LB-R             3.8750-02  -9.1211-02     -0.2354     -0.2241     -0.5412
DENSITY:
  LBMOL/CUFT           2.5162-03   1.7186-02   3.1758-02   1.1075-02      0.1018
  LB/CUFT              7.2593-02      0.4958      0.9162      0.3195      2.9364
AVG MW                   28.8504     28.8504     28.8504     28.8504     28.8504

306 307 308 309 310
-------------------
```

STREAM ID	306	307	308	309	310
FROM :	HPC	HPC	LPC	LPC	LPC
TO :	LPC	LPC	MHX2	MHX2	MHX2
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
OXYGEN	20.9993	2201.2603	2224.7852	497.3315	55.7076
NITROGEN	2935.2447	5424.6843	125.2148	4002.6685	6322.0281
METHANE	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	2956.2440	7625.9445	2350.0000	4500.0000	6377.7357
LB/HR	8.2898+04	2.2240+05	7.4698+04	1.2804+05	1.7888+05
CUFT/HR	1876.3850	4529.3597	1097.0931	2.9129+05	4.1266+05
STATE VARIABLES:					
TEMP F	-284.5198	-278.9830	-288.7385	-308.2283	-312.6017
PRES PSIA	92.0000	93.3000	27.3200	23.7200	23.0000
VFRAC	0.0	0.0	0.0	1.0000	1.0000
LFRAC	1.0000	1.0000	1.0000	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-4690.2072	-4799.9267	-5387.8371	-2719.8030	-2749.9823
BTU/LB	-167.2578	-164.5848	-169.5011	-95.5862	-98.0446
BTU/HR	-1.3865+07	-3.6604+07	-1.2661+07	-1.2239+07	-1.7539+07
ENTROPY:					
BTU/LBMOL-R	-23.4715	-22.4895	-25.1940	-9.2213	-9.9594
BTU/LB-R	-0.8370	-0.7711	-0.7926	-0.3241	-0.3551
DENSITY:					
LBMOL/CUFT	1.5755	1.6837	2.1420	1.5448-02	1.5455-02
LB/CUFT	44.1798	49.1023	68.0873	0.4396	0.4335
AVG MW	28.0418	29.1639	31.7865	28.4539	28.0483

311 312 313 TESTFEED TESTHPC

STREAM ID	311	312	313	TESTFEED	TESTHPC
FROM :	MHX1	MHX1	MHX1	MHX1	SPLITTER
TO :	----	----	----	MHX2	MHX1
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR					
OXYGEN	2224.7852	497.3315	55.7076	2222.2596	2222.2596
NITROGEN	125.2148	4002.6685	6322.0281	8359.9290	8359.9290
METHANE	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	2350.0000	4500.0000	6377.7357	1.0582+04	1.0582+04
LB/HR	7.4698+04	1.2804+05	1.7888+05	3.0530+05	3.0530+05
CUFT/HR	5.9091+05	1.0979+06	1.6049+06	3.1794+05	6.1574+05
STATE VARIABLES:					
TEMP F	80.0000	80.0000	80.0000	-162.7559	95.0000
PRES PSIA	23.0000	23.7200	23.0000	102.0000	102.0000
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	14.7239	15.4395	15.7264	-1736.1408	102.9280
BTU/LB	0.4632	0.5426	0.5607	-60.1774	3.5676
BTU/HR	3.4601+04	6.9478+04	1.0030+05	-1.8372+07	1.0892+06
ENTROPY:					
BTU/LBMOL-R	-0.4461	-0.2302	-0.7595	-7.0984	-2.6315
BTU/LB-R	-1.4036-02	-8.0906-03	-2.7077-02	-0.2460	-9.1211-02
DENSITY:					
LBMOL/CUFT	3.9769-03	4.0988-03	3.9740-03	3.3284-02	1.7186-02
LB/CUFT	0.1264	0.1166	0.1115	0.9603	0.4958
AVG MW	31.7865	28.4539	28.0483	28.8504	28.8504

TESTLPC TESTN2 TESTO2 TESTWAST

STREAM ID	TESTLPC	TESTN2	TESTO2	TESTWAST
FROM :	SPLITTER	MHX2	MHX2	MHX2
TO :	MHX1	MHX1	MHX1	MHX1
SUBSTREAM: MIXED				
PHASE:	VAPOR	VAPOR	VAPOR	VAPOR
COMPONENTS: LBMOL/HR				
OXYGEN	555.5649	55.7076	2224.7852	497.3315
NITROGEN	2089.9822	6322.0281	125.2148	4002.6685
METHANE	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0
TOTAL FLOW:				
LBMOL/HR	2645.5471	6377.7357	2350.0000	4500.0000
LB/HR	7.6325+04	1.7888+05	7.4698+04	1.2804+05
CUFT/HR	1.5394+05	8.2405+05	2.5457+05	5.6347+05
STATE VARIABLES:				
TEMP F	95.0000	-180.0000	-180.0000	-180.0000
PRES PSIA	102.0000	23.0000	27.3200	23.7200
VFRAC	1.0000	1.0000	1.0000	1.0000
LFRAC	0.0	0.0	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0
ENTHALPY:				
BTU/LBMOL	102.9280	-1803.1912	-1811.2572	-1804.2589
BTU/LB	3.5676	-64.2888	-56.9821	-63.4098
BTU/HR	2.7230+05	-1.1500+07	-4.2565+06	-8.1192+06
ENTROPY:				
BTU/LBMOL-R	-2.6315	-5.3603	-5.4042	-4.8330
BTU/LB-R	-9.1211-02	-0.1911	-0.1700	-0.1699
DENSITY:				
LBMOL/CUFT	1.7186-02	7.7395-03	9.2312-03	7.9862-03
LB/CUFT	0.4958	0.2171	0.2934	0.2272
AVG MW	28.8504	28.0483	31.7865	28.4539