LETTER OF TRANSMITTAL

April 2nd, 2020
Oklahoma State University
The School of Chemical Engineering
AIChE Student Design Competition Report

To Whom It May Concern,

Our team has submitted a preliminary design for a modular distributed ammonia synthesis plant, in the Minnesota River Valley.

The plant produces 53.5 metric tones of ammonia per day, at a purity of at least 99.5% (by mass), as requested in the memorandum. The process utilizes energy efficient processes and renewable energy in order to create the smallest environmental footprint possible.

Per your request, economic analysis has been performed over the standard twenty-year project life to identify the most profitable ammonia synthesis process. We have included our analysis of different ammonia processes and concluded that Haber Bosch process is the most attractive choice in terms of safety, economics, and design.

We conclude that this process will require a capital investment of $56 million. Annual operating costs will be $1.2 million. The payback period is 14 years, and the project produces a DCFROR of 3.6%.

If you have any other questions, please feel free to contact us.

Regards,

Savannah Robisch, Jake Thomas, Gentry Myer, and Seth Hart

CHE 4224

Spring 2020

AIChE National Student Design Competition

Modular Distributed Ammonia Synthesis

April 2, 2020

Group Number: 2

EXECUTIVE SUMMARY

In the United States ammonia is primarily produced along the Gulf Coast due to the availability of cheap, abundant natural gas. However, the majority of the ammonia is used for fertilizer and shipped to agricultural regions. Shipping is expensive and can lead to hazardous or dangerous incidents. An option to change the current ammonia supply chain includes designing a clean, modular ammonia plant capable of producing 50 mtpd in the Minnesota River Valley.

Designing the plant required exploration and analysis of different processes in clean, modular ammonia synthesis. Various process design elements were considered, but ultimately the most inherently safe, clean, and economically attractive processes were chosen. The ammonia plant design consists of nitrogen generation via pressure swing adsorption, hydrogen generation via electrolysis of water, anhydrous ammonia synthesis via the Haber Bosch process, and the installation of a wind farm to decrease the overall electricity cost.

The capital cost to construct a grassroots modular facility in the Minnesota River Valley is estimated to be $63.9 million. The ammonia production process consists of 12 compressors, 15 heat exchangers, 10 electrolyzers, 6 vessels, 2 adsorbers, 1 plug flow reactor, 1 water purifier, and 1 ammonia storage tank. All of the equipment was designed for a modular purpose. A total of 15 operators will be needed for an annual cost of $898 thousand. The utility costs are estimated to be around $1.23 million. The utility costs were mitigated with the addition of the wind farm to cover the electricity needs of the plant. Once becoming more aware of the location and current legislation, tax breaks and incentives for environmentally friendly process plants will be considered. Due to extra capital cost being invested into a more environmentally aware production facility, tax incentives will be advantageous to plant value. The project has an annual revenue of $14.6 million, a 20-year useful plant life, and minimum acceptable rate of return of 8%. The NPV of the project is $21.8 million with a DCFROR of 3.66% and payback period of 14 years. The process is economically attractive but not viable under current circumstances due to such large deviation within the sensitivity analysis.

Table of Contents

EXECUTIVE SUMMARY 2
INTRODUCTION 7
PROCESS FLOW DIAGRAM AND MATERIAL BALANCES 9
PROCESS DESCRIPTION 15
- Design Basis 15
- Design Philosophy 16
- Upstream Process 18
- Downstream Process 21

ENERGY BALANCE AND UTILITY REQUIREMENTS 23
EQUIPMENT LIST AND UNIT DESCRIPTIONS 23
EQUIPMENT SPECIFICATION SHEETS 25
EQUIPMENT COST SUMMARY 34
FIXED CAPITAL INVESTMENT SUMMARY 36
SAFETY, HEALTH, AND ENVIRONMENTAL CONSIDERATIONS 37
PROCESS SAFETY CONSIDERATIONS 37
- High Pressure 37
- Low Temperature 38
- Chemical Hazards 38
- Initial Interaction Matrix 39

OTHER IMPORTANT CONSIDERATIONS 44
MANUFACTURING/OPERATION COSTS (EXCLUSIVE OF CAPITAL REQUIREMENTS) 44
- Utility Costs 44
- Raw Material Cost and Usage 44

ECONOMIC ANALYSIS 48
- Capital Cost Estimates 48
- Revenue Estimates 49
- Operating Cost Estimates 50
- DCFROR Analysis 51

CASH FLOW DIAGRAMS *52*

Sensitivity Analysis 52

CONCLUSIONS *53*

RECCOMMENDATIONS *53*

ACKNOWLEDGEMENTS *54*

BIBLIOGRAPHY *54*

APPENDIX *56*

Appendix A: Equations 56

Figures and Tables

Figure 1: US Ammonia Production *7*

Figure 2: US Stranded Wind Energy *7*

Figure 3: Block Diagram for Anhydrous Ammonia Plant *8*

Figure 4: Hydrogen Process Flow Diagram *9*

Figure 5: Nitrogen Process Flow Diagram *10*

Figure 6: Ammonia Process Flow Diagram *11*

Figure 7: Ammonia Process Flow Diagram Continued *12*

Table 1: Stream Summary Table *13*

Table 2: Stream Summary Table Continued *14*

Table 3: Breakdown of Chemical Process Methods *15*

Table 4: Component Prices *16*

Table 5: Utility Costs *16*

Table 6: Utility Specifications *16*

Table 7 - Specifications of On Site Gas N-2900-TGN Model Adsorber *19*

Figure 8: Electrolyzer Capital Cost Information *20*

Table 8: Electrolyzer Utility Usage *21*

Table 9: Activation Energies *22*

Table 10: Heat Transfer Coefficients *22*

Table 11: Utility Summary *23*

Table 12: Process Equipment List and Unit Descriptions *24*

Table 13: Electrolyzer Spec Sheet *25*

Table 14: Mist Eliminator Vessel Spec Sheet *26*

Table 15: Carbon Filter Spec Sheet *26*

Table 15: Air Buffer Tank Spec Sheet *27*

Table 16: Nitrogen Pressure Swing Adsorber Spec Sheet *27*

Table 17: Nitrogen Buffer Vessel Spec Sheet *28*

Table 18: Ammonia Separator Spec Sheet *28*

Table 19: Ammonia Reactor Spec Sheet *29*

Table 20: Ammonia Storage Tank Spec Sheet......29
Table 21: Air Compressor Spec Sheet......30
Table 22: Nitrogen Compressor Spec Sheet......30
Table 22: Hydrogen Compressor Spec Sheet......31
Table 23: Feed Compressor Spec Sheet......31
Table 24: Refrigeration Compressor Spec Sheet......32
Table 25: Feed/Effluent Exchanger Spec Sheet......32
Table 26: Ammonia Condenser Spec Sheet......33
Table 27: Refrigeration Cooler Spec Sheet......34
Table 28: Equipment Cost Summary......35
Figure 9: Equipment Cost Summary......36
Table 29: Net Present Value Best/Worst Case......36
Table 30: Operating Costs......36
Table 31: Chemical Hazard Summary......38
Figure 10: Interaction Matrix......40
Table 32: Inventory Update......41
Table 33: Material Properties......42
Table 34: Potential Consequence Summary......43
Table 35: Hazard Summary......43
Table 36: Utility Cost......44
Table 37: Raw Material Cost and Usage......44
Table 38: Cash Flow Diagram......46
Table 39: Capital Cost Table......48
Table 40: Revenue Summary......50
Table 41: Operating Labor Costs......50
Table 42: Operating Costs Summary......51
Table 43: Economic Analysis......51
Figure 11: Sensitivity Analysis......52
Table 44: Sensitivity Analysis......53

INTRODUCTION

Ammonia is sustaining the food supply for half the world's population. With world population expected to grow by over a third, or 2.3 billion people, between 2009 and 2050 [1], ammonia demand will grow with new food production needs. As seen in Figure 1, ammonia revenue is projected to almost double by 2025 in the United States, spurring future production. With current ammonia manufacturing accounting for 3% of the world's energy consumption, and 3% of greenhouse gas emissions, creating a sustainable and affordable method of synthesis is of the utmost importance considering potential future growth [2].

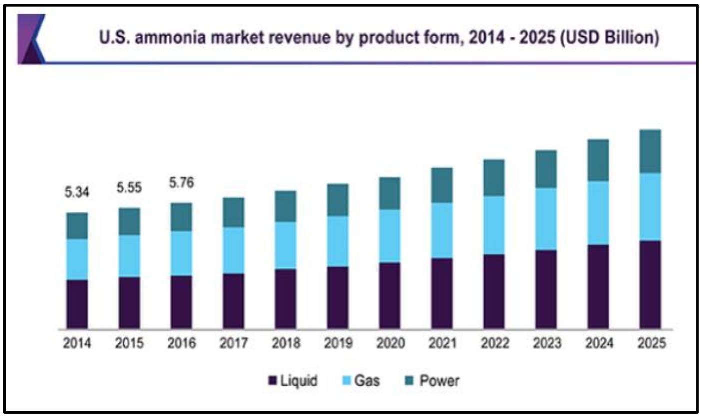


Figure 1: US Ammonia Production

Considering the growing supply of ammonia demand, a recent surge in renewable wind power in the western Minnesota River Valley, has created the opportunity for environmentally friendly ammonia production. The surge in renewable energy is due to stranded wind, Figure 2, finally being utilized by Minnesota power companies [3]. The Minnesota River Valley is near a main american agricultural region, making this a great location for an ammonia plant. Production near the US Corn Belt will allow for decreased transportation costs, less safety risks, and lower emissions. Utilizing renewable energy will allow for a smaller carbon footprint, and provide the plant with positive economic repercussions.

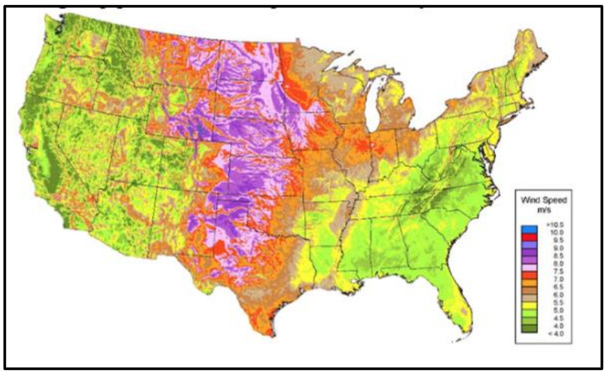


Figure 2: US Stranded Wind Energy

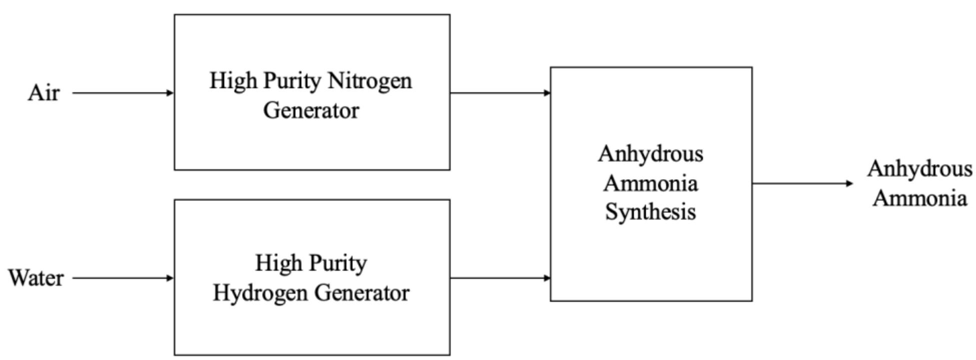
In addition to utilizing renewable energy, it has been requested the design be cognizant of new modular manufacturing methods. Modular manufacturing can offer advantages in terms of time-to-market, and economies of mass production. It is possible a modular design may become economically and technically feasible enough for farms to utilize their own small scale ammonia synthesis process in the future.

The goal of this project is to perform a preliminary design, estimate the costs, and evaluate the economics for the potential of a small scale modular ammonia plant. The design team has analyzed traditional ammonia synthesis and streamlined it. Traditionally ammonia is produced by the Haber-Bosch process, but utilizing absorption columns, non-thermal plasma, and streamlining gas purification steps were all analyzed as well. The ammonia reaction chemistry utilizes nitrogen and hydrogen intermediates, which are produced from upstream feedstocks at the proposed plant. Nitrogen can be produced by cryogenic distillation, pressure swing adsorption, or membranes. Hydrogen can be produced by steam methane reforming or the electrolysis of water.

The design basis of this project was to create the most efficient plant, capable of creating 50 metric tones per day of 99.5% purity (by mass) ammonia. The modular manufacturing methods were considered to maximize the efficiency of the process, and reach the required daily flow rate of the product. Renewable energy was considered in order to lower the carbon footprint of the plant, and adhere to EPA regulations. After processing, products will be sent directly to farmers in the region. Any excess will be kept in storage tanks on site, but not more to comprise inherent safety of the personnel, plant, and environment.

The business basis for the project was to minimize capital and operating costs, while increasing the profit from ammonia production. This project assumes year round production, and will use process intensification to lower equipment costs. The plant has a 20 year life expectancy, and will be considered for the 2020 capital budget, with construction set to begin in Q4 of 2021, with startup occurring mid-year 2022. The team objective was to find the most economically attractive design by analyzing the profits of anhydrous ammonia in the Minnesota River Valley. All economic considerations account for depreciation, write offs, inflation, and taxes. The net present value, rate of return, and payback period help evaluate the economic feasibility for this project. In addition, a sensitivity analysis was performed to assess the risk associated with different aspects of the project. An overview of the process is highlighted in Figure 3.

Figure 3: Block Diagram for Anhydrous Ammonia Plant



PROCESS FLOW DIAGRAM AND MATERIAL BALANCES

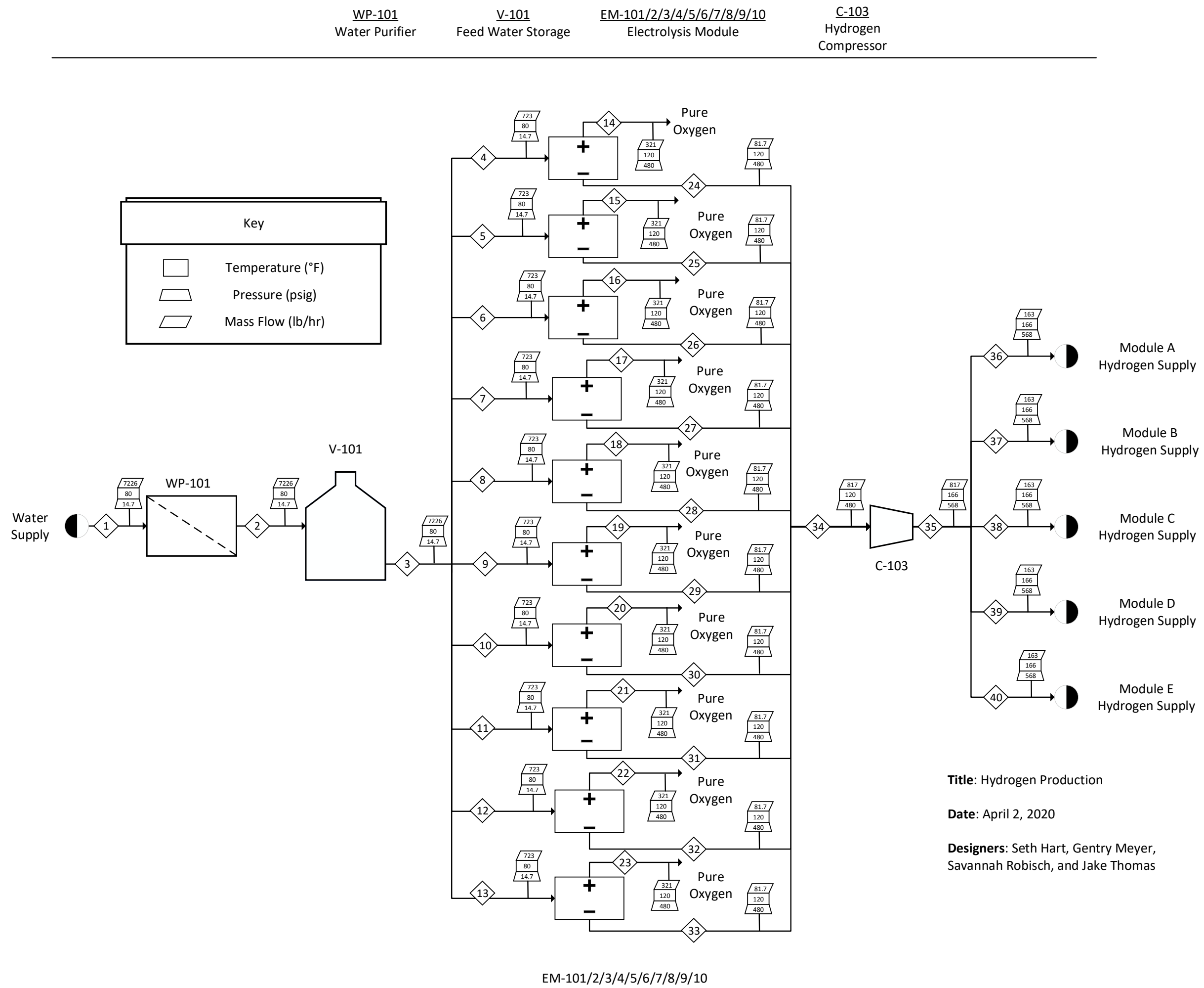


Figure 4: Hydrogen Process Flow Diagram

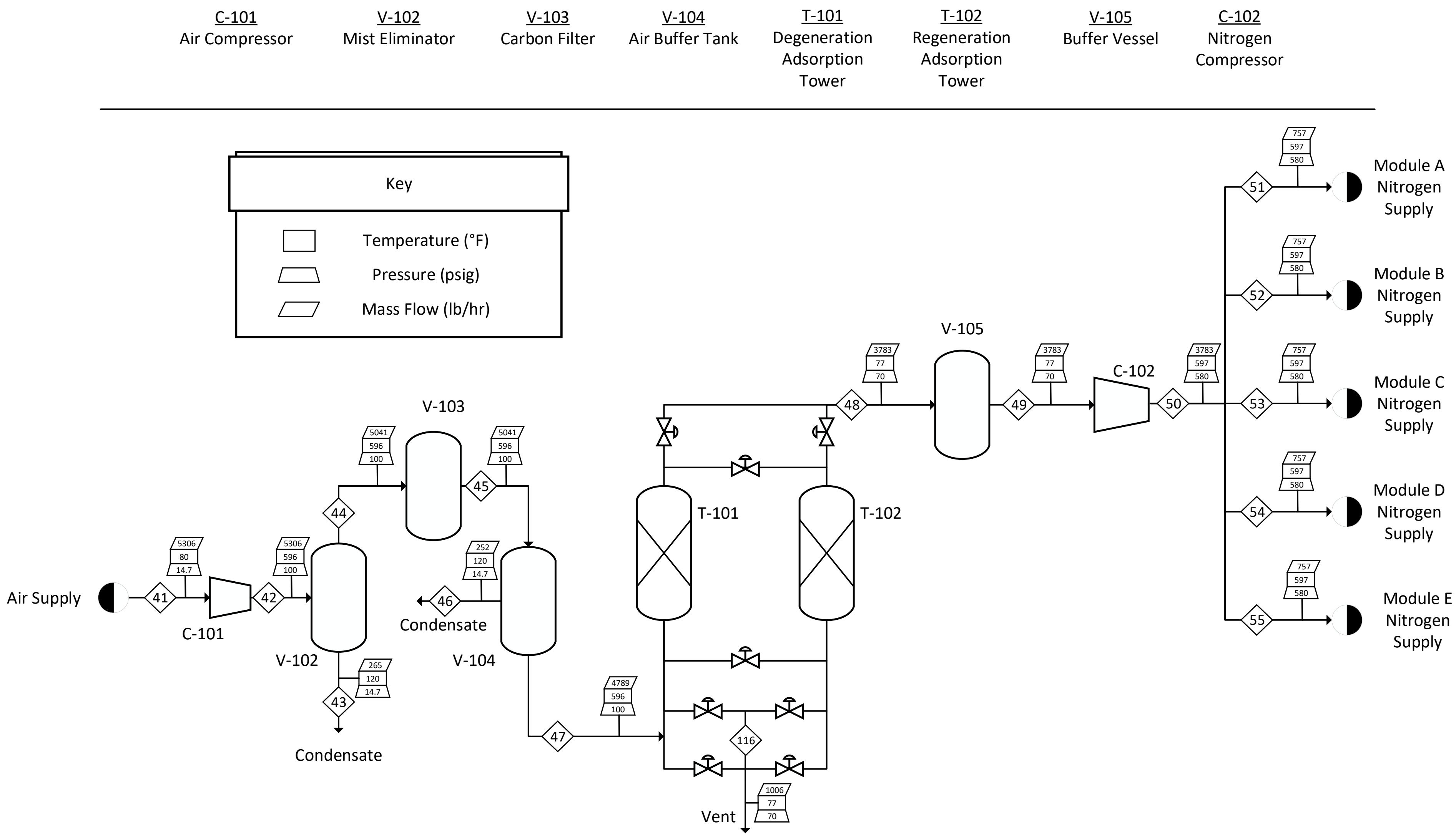


Figure 5: Nitrogen Process Flow Diagram

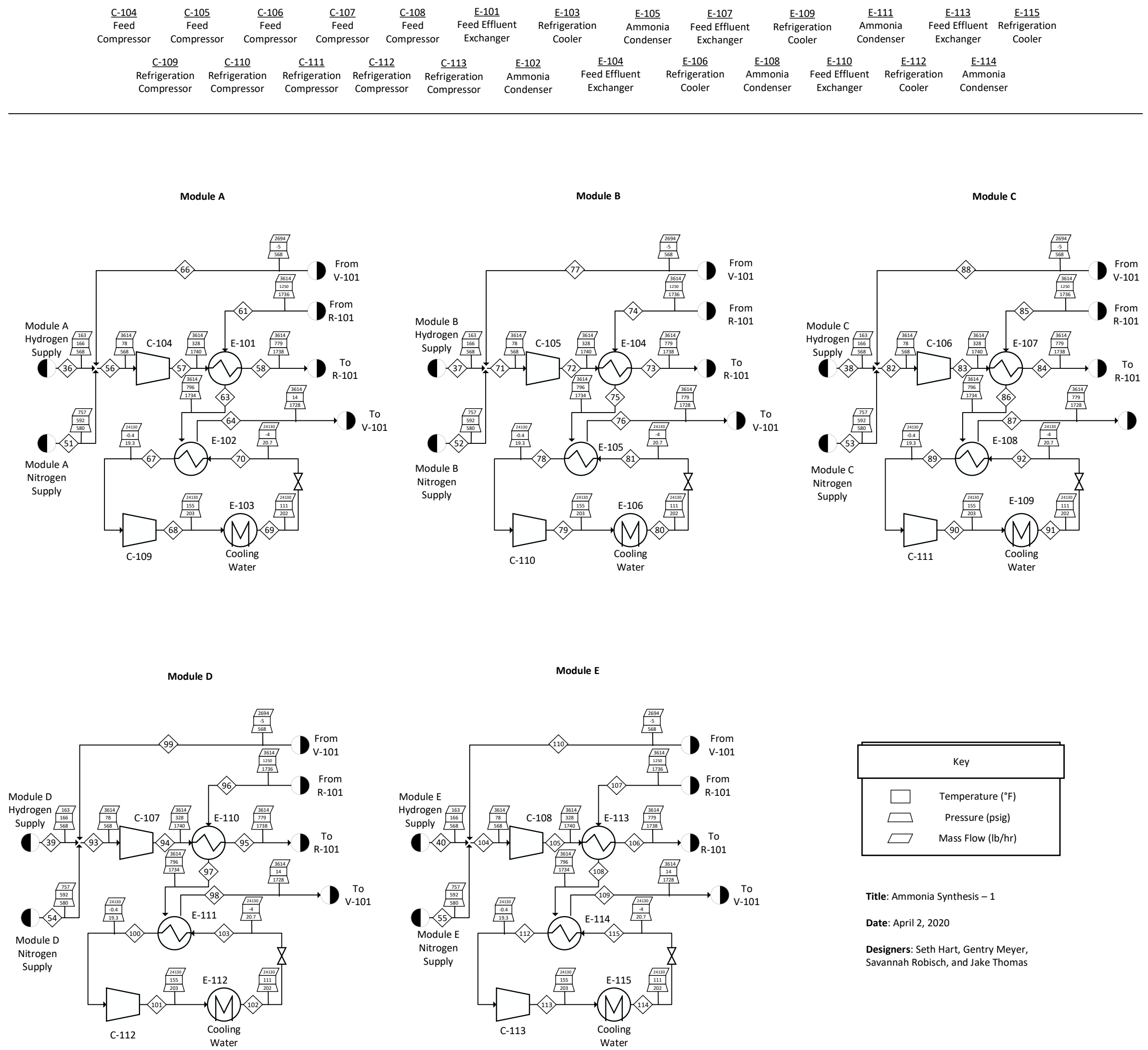


Figure 6: Ammonia Process Flow Diagram

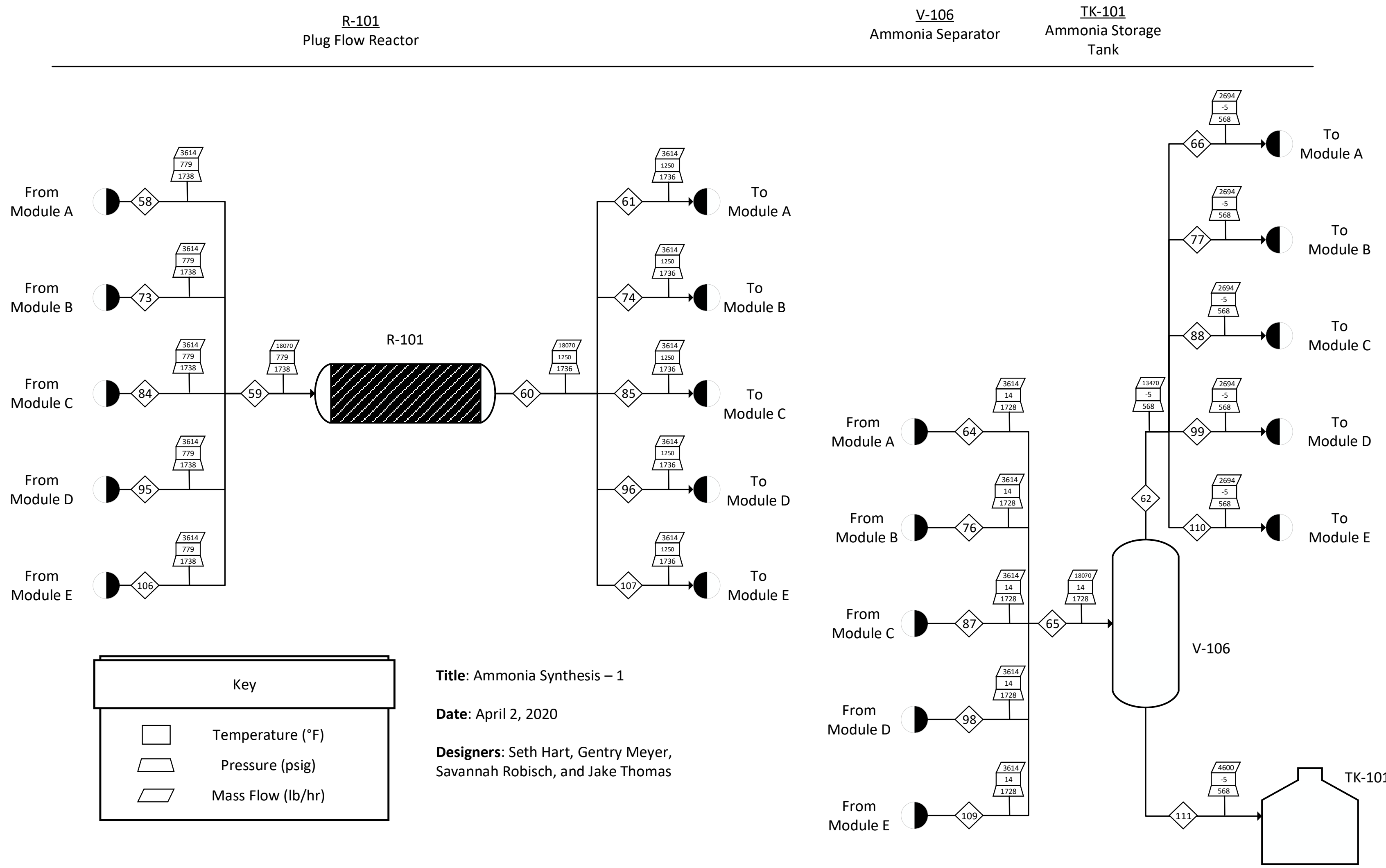


Figure 7: Ammonia Process Flow Diagram Continued

Table 1: Stream Summary Table

Stream		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Vapour Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Temperature	F	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	119.5	119.5	119.5	119.5	119.5	119.5	119.5	119.5	119.5	119.5	119.5
Pressure	psig	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0
Mass Flow	lb/hr	7226.0	7226.0	7226.0	722.6	722.6	722.6	722.6	722.6	722.6	722.6	722.6	722.6	722.6	320.8	320.8	320.8	320.8	320.8	320.8	320.8	320.8	320.8	320.8	81.7
Volumetric Flowrate	USGPM	14.5	14.5	14.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	2.3
Density	lb/ft3	62.81	62.81	62.81	62.81	62.81	62.81	62.81	62.81	62.81	62.81	62.81	62.81	62.81	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	0.16
Air	lb/ft3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonia	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrogen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.7
Nitrogen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oxygen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	320.8	320.8	320.8	320.8	320.8	320.8	320.8	320.8	320.8	320.8	0.0
Propane	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	lb/hr	7226.0	7226.0	7226.0	723.0	723.0	723.0	723.0	723.0	723.0	723.0	723.0	723.0	723.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream		25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Vapour Fraction		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1
Temperature	F	119.5	119.5	119.5	119.5	119.5	119.5	119.5	119.5	119.5	119.5	166.0	166.0	166.0	166.0	166.0	166.0	80.0	596.0	120.0	596.0	596.0	120.0	596.0	77.0
Pressure	psig	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	568.0	568.0	568.0	568.0	568.0	568.0	14.7	100.0	14.7	100.0	100.0	14.7	100.0	70.0
Mass Flow	lb/hr	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	816.5	816.5	163.3	163.3	163.3	163.3	163.3	5306.0	5306.0	265.0	5041.0	5041.0	252.0	4789.0	3783.0
Volumetric Flowrate	USGPM	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	23.0	23.3	4.7	4.7	4.7	4.7	4.7	8725.4	2241.1	0.5	2143.9	2143.9	0.5	2036.7	12.0
Density	lb/ft3	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.19	0.19	0.19	0.19	0.19	0.19	0.08	0.29	62.40	0.29	0.29	62.40	0.29	1.00
Air	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5306.0	5306.0	0.0	5041.0	5041.0	0.0	4789.0	0.0
Ammonia	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrogen	lb/hr	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	817.0	816.5	163.3	163.3	163.3	163.3	163.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitrogen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3783.0
Oxygen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	265.0	0.0	0.0	252.0	0.0	0.0

Stream		49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
Vapour Fraction		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.8103	0.8103	1	1	1	0	0.4259	1	1
Temperature	F	77.0	596.7	596.7	596.7	596.7	596.7	596.7	78.0	329.1	779.0	779.0	1250.0	1250.0	-5.0	795.6	14.0	14.0	-5.0	-0.4	154.8	110.5	-4.0	78.0	329.1
Pressure	psig	70.0	580.2	580.2	580.2	580.2	580.2	580.2	568.0	1740.0	1738.0	1738.0	1736.0	1736.0	568.0	1734.0	1728.0	1728.0	568.0	19.3	203.1	201.6	20.7	568.0	1740.0
Mass Flow	lb/hr	3783.0	3783.0	756.5	756.5	756.5	756.5	756.5	3614.0	3614.0	3614.0	18070.0	18070.0	3614.0	13470.0	3614.0	3614.0	18070.0	2694.0	24130.0	24130.0	24130.0	24130.0	3614.0	3614.0
Volumetric Flowrate	USGPM	12.0	2.0	1.9	1.9	1.9	1.9	1.9	22.1	22.1	22.1	110.0	95.0	18.5	77.6	18.5	18.5	92.6	15.5	95.1	96.1	95.1	95.1	22.1	22.1
Density	lb/ft3	1.00	1.00	1.45	1.45	1.45	1.45	1.45	1.02	1.99	1.27	1.27	1.09	1.09	1.27	1.48	4.71	4.71	1.27	0.32	1.80	28.79	0.79	1.02	1.99
Air	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonia	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	244.7	244.7	244.7	1225.0	5816.3	1163.3	1223.7	1163.3	1163.3	5816.3	244.7	0.0	0.0	0.0	0.0	244.7	244.7
Hydrogen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	494.6	495.0	495.0	2475.0	1659.3	331.9	1658.1	331.9	331.9	1659.3	331.6	0.0	0.0	0.0	0.0	494.6	495.0
Nitrogen	lb/hr	3783.0	3783.0	756.5	756.5	756.5	756.5	756.5	2874.5	2874.5	2874.5	14370.0	10595.2	2119.0	10589.8	2119.0	2119.0	10595.2	2118.0	0.0	0.0	0.0	0.0	2874.5	2874.5
Oxygen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24131.0	241301.0	241301.0	24130.9	0.0	0.0
Water	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream		73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Vapour Fraction		1	1	1	0.8103	1	1	1	0	0.4259	1	1	1	1	1	0.8103	1	1	1	0	0.4259	1	1	1	1
Temperature	F	779.0	1250.0	795.6	14.0	-5.0	-0.4	154.8	110.5	-4.0	78.0	329.1	779.0	1250.0	795.6	14.0	-5.0	-0.4	154.8	110.5	-4.0	78.0	329.1	779.0	1250.0
Pressure	psig	1738.0	1736.0	1734.0	1728.0	568.0	19.3	203.1	201.6	20.7	568.0	1740.0	1738.0	1736.0	1734.0	1728.0	568.0	19.3	203.1	201.6	20.7	568.0	1740.0	1738.0	1736.0
Mass Flow	lb/hr	3614.0	3614.0	3614.0	3614.0	2694.0	24130.0	24130.0	24130.0	24130.0	3614.0	3614.0	3614.0	3614.0	3614.0	3614.0	2694.0	24130.0	24130.0	24130.0	24130.0	3614.0	3614.0	3614.0	3614.0
Volumetric Flowrate	USGPM	22.1	18.5	18.5	18.5	15.5	95.1	96.1	95.1	95.1	22.1	22.1	22.1	18.5	18.5	18.5	15.5	95.1	96.1	95.1	95.1	22.1	22.1	22.1	18.5
Density	lb/ft3	1.27	1.09	1.48	4.71	1.27	0.32	1.80	28.79	0.79	1.02	1.99	1.27	1.09	1.48	4.71	1.27	0.32	1.80	28.79	0.79	1.02	1.99	1.27	1.09
Air	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonia	lb/hr	244.7	1163.3	1163.3	1163.3	244.7	0.0	0.0	0.0	0.0	244.7	244.7	244.7	1163.3	1163.3	1163.3	244.7	0.0	0.0	0.0	0.0	244.7	244.7	244.7	1163.3
Hydrogen	lb/hr	495.0	331.9	331.9	331.9	331.6	0.0	0.0	0.0	0.0	494.6	495.0	495.0	331.9	331.9	331.9	331.6	0.0	0.0	0.0	0.0	494.6	495.0	495.0	331.9
Nitrogen	lb/hr	2874.5	2119.0	2119.0	2119.0	2118.0	0.0	0.0	0.0	0.0	2874.5	2874.5	2874.5	2119.0	2119.0	2119.0	2118.0	0.0	0.0	0.0	0.0	2874.5	2874.5	2874.5	2119.0
Oxygen	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	lb/hr	0.0	0.0	0.0	0.0	0.0	24131.0	241301.0	241301.0	24130.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24131.0	241301.0	241301.0	24130.9	0.0	0.0	0.0	0.0
Water	lb/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2: Stream Summary Table Continued

Stream		97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
Vapour Fraction		1	0.8103	1	1	1	0	0.4259	1	1	1	1	1	0.81	1	0	1	1	0	0.43	1
Temperature	*F*	795.6	14.0	-5.0	-0.4	154.8	110.5	-4.0	78.0	329.1	779.0	1250.0	795.6	14.0	-5.0	-5.0	-0.4	154.8	110.5	-4.0	77.0
Pressure	*psig*	1734.0	1728.0	568.0	19.3	203.1	201.6	20.7	568.0	1740.0	1738.0	1736.0	1734.0	1728.0	568.0	568.0	19.3	203.1	201.6	20.7	70.0
Mass Flow	*lb/hr*	3614.0	3614.0	2694.0	24130.0	24130.0	24130.0	24130.0	3614.0	3614.0	3614.0	3614.0	3614.0	3614.0	2694.0	4600.0	24130.0	24130.0	24130.0	24130.0	1006.0
Volumetric Flowrate	*USGPM*	18.5	18.5	15.5	95.1	96.1	95.1	95.1	22.1	22.1	22.1	18.5	18.5	18.5	15.5	14.9	95.1	96.1	95.1	95.1	150.0
Density	*lb/ft3*	1.48	4.71	1.27	0.32	1.80	28.79	0.79	1.02	1.99	1.27	1.09	1.48	4.71	1.27	41.06	0.32	1.80	28.79	0.79	0.82
Air	*lb/hr*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonia	*lb/hr*	1163.3	1163.3	244.7	0.0	0.0	0.0	0.0	244.7	244.7	244.7	1163.3	1163.3	1163.3	244.7	4594.9	0.0	0.0	0.0	0.0	0.0
Hydrogen	*lb/hr*	331.9	331.9	331.6	0.0	0.0	0.0	0.0	494.6	495.0	495.0	331.9	331.9	331.9	331.6	0.2	0.0	0.0	0.0	0.0	0.0
Nitrogen	*lb/hr*	2119.0	2119.0	2118.0	0.0	0.0	0.0	0.0	2874.5	2874.5	2874.5	2119.0	2119.0	2119.0	2118.0	4.0	0.0	0.0	0.0	0.0	0.0
Oxygen	*lb/hr*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1005.7
Propane	*lb/hr*	0.0	0.0	0.0	24131.0	241301.0	241301.0	24130.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24131.0	241301.0	241301.0	24130.9	0.0
Water	*lb/hr*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PROCESS DESCRIPTION

Design Basis

The dependence on ammonia for US agriculture reveals the industry could be an attractive and stable option for development. The design team fulfilled the request to design a new small scale ammonia plant near the US corn belt. Anhydrous ammonia production has been performed utilizing the Haber Bosch process since its inception and implementation in 1912 by Fritz Haber and Carl Bosch [4]. The process utilizes the reaction chemistry in Reaction 1.

$$(1) \qquad N_2 + 3H_2 \leftrightarrow 2NH_3$$

Aside from the ammonia synthesis reaction, there are necessary support processes for nitrogen and hydrogen production upstream. The method of performing the upstream processes varies vastly across industry and considerations of each method are detailed in the design basis.

The anhydrous ammonia plant was designed using ASPEN HYSYS version 10 with Peng-Robinson as the equation of state. This software is an industry standard for designing process equipment. Equipment unable to be designed in ASPEN HYSYS 10 was designed and sized using vendor specifications. The safety, efficiency, and feasibility of the synthesis plant were the basis for our design. Each individual process was optimized separately before being combined into one large plant. This allowed for safety precautions, cost savings, and implementation of modular design to the best extent. Each process design method is listed in Table 3.

Table 3: Breakdown of Chemical Process Methods

Chemical Process	Methods Considered
Nitrogen Generation	Cryogenic Distillation
	Pressure Swing Adsorption
	Membrane Separation
Hydrogen Generation	Steam Methane Reforming
	Electrolysis of Water
Anhydrous Ammonia Synthesis	Haber Bosch Process
	Combining Synthesis Reaction with Ammonia Absorption
	Non-Thermal Plasma
	Streamlining Water-Gas Shift Reactor and Gas Purification Steps

This process is required to produce 53.5 metric tones per day of anhydrous ammonia at a purity of 99.5% by mass. The product will be produced year round and sold to local ammonia consumers, to decrease transportation costs. The design produced the lowest possible carbon footprint, and utilized stranded wind energy as requested. The project was analyzed with a 20 year plant life in mind and an 8% minimum rate of return on the project. The process components are priced according to industry standards, as in Table 4.

Table 4: Component Prices

Component	Purity	Price	Unit
Ammonia [12]	99.50%	$685	$/USton
Oxygen [17]	99.95%	$40	$/USton
Feed Water [5]	-	$0.06	$/1000 USgal

In order to properly account for project economics, utility rates were found for southwestern Minnesota. The prices for utilities are listed in Table 5. Electricity is not mentioned in the utility cost due to on-site wind production.

Table 5: Utility Costs

Mode	Cost	Unit
Cooling Water [5]	$0.06	$/1000 USgal
Propane [16]	$6	$/kg

The utility specifications are listed in Table 6. The restrictions are due to the capabilities of the site, the physical properties of the utilities, or Minnesota utility parameters.

Table 6: Utility Specifications

Extreme Maximum Temperature of Water (°F)	107
Extreme Minimum Temperature of Propane (°F)	-5
Absolute Atmospheric Pressure (psia)	14.7
Cooling Water Supply Temperature (°F) [15]	77
Cooling Water Return Temperature (°F)	107
Cooling Water Supply Pressure (psig)	14.7

Design Philosophy

Many factors are taken into account when designing a chemical process. Physical, technical, and environmental restraints are necessary throughout the process, in order to create an accurate and safe design. All major assumptions and heuristics utilized throughout the design are documented below.

Compressors

- Efficiencies of large centrifugal compressors (6000-100,000 acfm) at suction are 76-78% [5].
- Dynamic, centrifugal compressors are better for high flow rates than positive displacement compressors.
- Flow rates for centrifugal compressors have surge and stonewall conditions.
- Centrifugal compressors are limited to a compression ratio of ~1.5-2.75/wheel.
- Compressors have low tolerance for liquids, so inlet streams must be prepped accordingly.

Compressor Drivers

- Combustion engines and turbines are restricted to mobile and remote locations [5].
- Electric motors are 85-95% efficient [5].

Pressure and Storage Vessels

- For less than 1000 gallons of storage use vertical tanks on legs.
- Between 1000-10,000 gallons of storage use horizontal tanks on concrete supports [5].
- Volume should be double the inlet flow rate after five minutes [5].

Heat Exchangers

- Tube side is for corrosive, fouling, scaling, and high-pressure fluids [5].
- Shell side is for viscous and condensing fluids [5].

Electrolyzers

- Maximum capacity of 900 kg-H_2 per day [18].
- Efficiency of 95% [19].

Miscellaneous Assumptions

- Service factor is 0.96.
- The modular design equation was applicable to any equipment needing to be replicated.
- The wash-out assumption was used in the cash flow table.

The design team focused on maintaining high safety standards, minimizing the environmental impact of production, and maximizing profit. Each process was analyzed individually in order to minimize capital investment, operating cost, and risk, while maximizing efficiency and profit. In order to create a small scale ammonia plant, all process components are created on site. Nitrogen is separated from air, and hydrogen is separated from water, before being used to synthesize anhydrous ammonia.

Upstream Process

Nitrogen Generation

The upstream process begins with the production of nitrogen from air. In order to separate nitrogen from air, it must be processed through a compressor, mist eliminator, carbon filter, and air buffer tank. The compressor, C-101, increases the air pressure from 14.7 psi to 100 psi. The mist eliminator, V-102, removes oil, solids and water molecules to increase the lifespan of the compressed air system. The carbon filter, V-103, removes molecules that are unable to be separated by the nitrogen generation process. Finally the compressed air is sent to an air buffer tank (V-104). This allows the air to lose any condensation to the waste stream, and ensures a constant supply of air to the nitrogen generation process. All of the aforementioned equipment serves to prepare the air in order to achieve the purity necessary for the ammonia synthesis reaction.

Once air is prepped for separation, it travels to the nitrogen generation equipment unit. When separating nitrogen from air, there are three main processes consistently used in industry: cryogenic distillation, pressure swing adsorption, and membrane separation. All three processes were researched and compared for process feasibility.

Cryogenic distillation uses a traditional distillation column at sub-zero temperatures in order to separate nitrogen from air by their flash points [20]. Cryogenic distillation is able to create high daily gas production volume (> 100 tones per day) at a purity greater than 99%. This method was not selected because only 20 tones per day is required for the ammonia synthesis process. Cryogenic distillation operating costs would also decrease the profit margin of the plant.

Membrane technology is an emerging gas separation technique. Air is drawn into a membrane unit, then targeted gases are separated based on their diffusivity and solubility. It has a lower cost in initial capital investment and energy consumption than other forms of air separation. However, membrane separation can only produce 10 - 25 tones of gas product per day, with low purities around 40% [20].

Pressure swing adsorption (PSA) utilizes high pressures, and adsorbents to separate gases based on molecule size. This process is ideal for application in this ammonia synthesis design because it produces medium range gas volumes, 20-100 tones per day, at purities up to 99.9995% [21].

Once the method of nitrogen generation was selected, the adsorption process was designed. The process was unable to be designed in the traditional ASPEN Hysys Version 10.0 so, ASPEN Adsorption was considered. However, the program required experimental data in order to design the adsorption columns. The team then began requesting vendor quotes of existing machinery. The best adsorbent to facilitate nitrogen separation from air is a carbon molecular sieve of 5A porosity.

Quotes were requested for pressure swing adsorption systems from Peak Scientific, Parker Hannifin, and On Site Gas. Peak Scientific was not chosen because they create small scale systems for laboratory settings. The number of PSA that would be needed to create 26,000 SCFH was unrealistic, and would likely have been far too expensive. Parker Hannifin's largest PSA system, DB-80, could create up to 5600 SCFH of nitrogen, however only at 99% purity. So this adsorber was not chosen.

On Site Gas had the largest pressure swing adsorber for sale, capable of processing 13,000 SCFH. The specifications for the adsorber are listed in Table 7.

Table 7 - Specifications of On Site Gas N-2900-TGN Model Adsorber

Adsorber N-2900-TGN	
Purity	99.99
Flow (SCFH)	13000
Outlet Pressure (psi)	70
Bed Package	V8 SKID
Bed Dimensions (in)	76" x 91" x 214"
Inlet Air Requirement (SCFM)	1007
Inlet Pressure (psi)	100
AMP Package	AMP-31500

Due to the flow rate of the OSG adsorber, only two would be required. Each PSA consists of two pressure vessels, for degeneration and regeneration of air. The vessel dimensions are 76" x 91" x 214". Due to economies of mass, the second adsorber will cost slightly less due to the learning curve. The two PSA units will run in parallel and will both require 2200 gallon nitrogen gas receivers afterwards. The receivers make the process inherently safer by creating a buffer zone after the PSA vessels. These receivers prevent a vacuum from forming if nitrogen supply suddenly drops.

<u>Hydrogen Generation</u>

Hydrogen feed for ammonia synthesis is produced via electrolysis, steam methane reformation, and by biomass gasification. The objective of the project was to design a process that produces ammonia free of carbon waste that is typically released to the atmosphere. Steam methane reformation utilizes natural gas and high temperature steam to produce hydrogen, carbon monoxide, and carbon dioxide [22]. The hydrocarbons generated in the process are released to the atmosphere, so steam methane reformation was not considered. Biomass gasification can be a clean method of producing hydrogen, but requires extended periods of time to produce the hydrogen needed for the process [23]. Clean hydrogen production from the gasification of biomass is feasible, but producing hydrogen using biomass is the most expensive method to date. Until the process is economically attractive biomass gasification can be ignored. Water electrolysis produces high purity hydrogen by splitting water with electricity. This method was considered for the project due to the clean production of hydrogen and the process did not require additional downstream equipment to increase the overall purity of the hydrogen stream. The electricity needed for the process is intensive, so electricity consumption and acquisition were examined.

In electrolysis, the water molecule is split by passing a current through two electrodes in water. High purity oxygen is produced at the anode while high purity hydrogen is produced at the cathode. The overall electrolysis system consists of a water purifier, water storage tank, and an electrolyzer unit. The water within the electrolyzer must be a high purity, so the water purifier ensures the water acquired for the process meets the purity specification. The process is continuous and does not require a water storage drum before the electrolyzer, but if the process water system is disrupted the water storage drum gives necessary time to resolve the disruption issue [18]. For the process one water purifier and water storage drum are used.

Multiple different electrolyzer designs were considered for the project, but ultimately a bipolar alkaline electrolyzer was chosen. The bipolar alkaline electrolyzer allows for a hydrogen production capacity up to 1500 kg-H_2 per day, does not require precious metal electrodes, and is one of the most efficient electrolyzer systems at 95% [19]. Other electrolyzers require precious metals for the electrodes, can be very energy inefficient, and have a production capacity of 250 kg-H_2 per day.

A panel reviewed companies that produced hydrogen via electrolysis in the United States. A vendor capital cost information graph was developed to account for the unit cost based on the kg-H_2 produced per day capacity. The electrolyzer units were split into two groups: forecourt and central plant. Forecourt is a hydrogen producing plant focused on the distribution of hydrogen to other corporations. Central plant is a hydrogen producing plant that utilizes the hydrogen produced further within the plant's other processes. The panel agreed unit costs for both forecourt and central plant are identical if the electrolyzer's production capacity is under 1000 kg-H_2 per day [18].

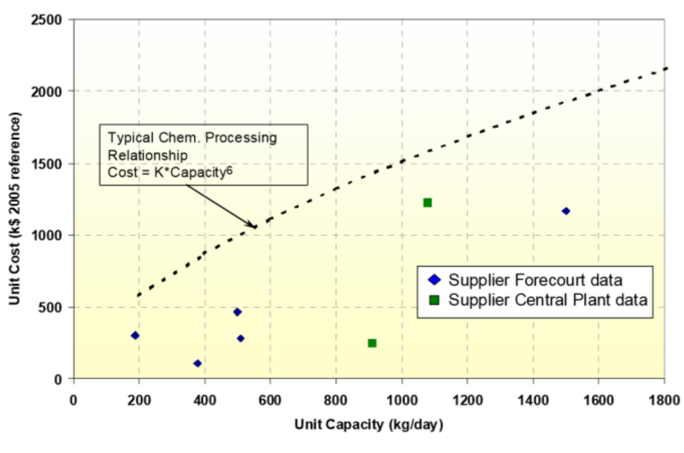


Figure 8: Electrolyzer Capital Cost Information

The electrolyzer hydrogen capacity chosen for the project was 900 kg-H_2 per day due to the lower unit cost at a higher unit capacity. To stay within this production capacity, the total hydrogen produced for the ammonia production of 8820 kg-H_2 per day was divided into 10 electrolyzers that would operate at 882 kg-H_2 per day. The operating conditions for the bipolar alkaline electrolyzer are 120 °F and 480 psig. The unit cost covers the electrolyzer, purifier, and water storage drum. The water storage drum was designed to account for the drum to be half way filled with water after 10 minutes.

The major utility for the electrolyzer is electricity. The electricity needed to produce 8820 kg-H_2 per day in kWh was solved by using the heat of formation of water and the moles of water needed for the desired hydrogen production [24].

Table 8: Electrolyzer Utility Usage

H_2O Std. Heat of Formation (kJ/mol)	-286
Water (mol/day)	4.37E+06
Energy (kJ/h)	5.20E+07
kWh (day)	3.47E+05
kWh (year)	1.27E+08

Downstream Process

Ammonia Synthesis

The Haber-Bosch process was chosen for the production of ammonia. Other practices, including ammonia absorption and non-thermal plasma catalysis, were considered. Ultimately, Haber-Bosch was chosen due to the conventionality of the small-scale plant operation. This downstream portion must be performed at high temperatures and pressures for the reaction to take place [5]. The specific catalyst chosen, AmoMax-10 (supplied by Clariant), is a ferrous oxide (wustite) catalyst with promoters [25]. This catalyst pushes the exothermic reaction to completion at a lower temperature and faster rate than would otherwise be possible while producing significant energy savings, improving conversion and reducing reduction time.

This process was designed using Aspen HYSYS. The recycle, hydrogen and nitrogen gas streams are first compressed and sent to the ammonia reactor to undergo the ammonia synthesis reaction. After conversion, the reactor outlet is sent to a condenser, which is part of a larger propane refrigeration cycle. The mixture is chilled to 14°F. This stream is fed into a knockout drum where separation takes place via pressure drop with a drum pressure of approximately 568 psig. The liquid anhydrous ammonia is then sent to tankage while the unreacted gaseous ammonia, nitrogen, and hydrogen are recycled back through the process. Once the ammonia product is condensed, the liquid-gas mixture is sent through a knockout drum where the condensed ammonia is separated and delivered to tankage. For this process, modular units should be purchased for all but the reactor and separator. These two pieces of equipment will serve all five process units in order to reduce capital cost and reduce the number of operators needed for each process. Each ammonia unit has the ability to produce 10mtpd - resulting in five units purchased for an ending product of 53 mtpd anhydrous ammonia.

The reaction is very dependent on the activation energy. Fluctuation of the catalyst-dependent properties increase or decrease the conversion rate and recycle. This results in a higher or lower rate of conversion. The conversion rate is the driving force for all areas of the equipment within the ammonia synthesis portion of the process. A higher rate of reaction will decrease the recycle stream; in turn, downsizing the equipment and saving money on capital and utility costs. Thus, small deviations of these numbers have a very large economic impact. Constants were not able to be obtained for the specific catalyst but for one similar shown in Table 9 [8]. Once catalyst specific activation energies are given for the purchased catalyst, capital cost has the potential to largely deviate and must be kept in mind moving forward with the project consideration.

Table 9: Activation Energies

A	17895
E (Btu/lbmol)	87027
A'	2.5714E+14
E' (Btu/lbmol)	198320

Table 10: Heat Transfer Coefficients

Component	**Uo (Btu/hr.ft^2.°F) [14]**
E-101, E-104, E-107, E-110, E-113	70
E-102, E-105, E-108, E-111, E-114	150
E-103, E-106, E-109, E-112, E-115	500

The ammonia condenser requires a refrigeration cycle to fully condense the reacted ammonia in the gas mixture. Striving to create an environmentally friendly process, propane is used as the refrigerant. This chemical poses a very small environmental impact. Propane has a non-existent Ozone Depletion Potential (ODP) and miniscule Global Warming Potential (GWP) [9].

ENERGY BALANCE AND UTILITY REQUIREMENTS

The amount of electricity used throughout the process is shown in Table 11.

Table 11: Utility Summary

Equipment	**Electric Power (kWh)**	**Cooling Water (m3/hr)**
EM-101, EM-102, EM-103, EM-104, EM-105, EM-106, EM-107, EM-108, EM-109, EM-110	3.47E+05	-
C-101	441	-
C-103	38	-
C-102	148	-
C-104, C-105, C-106, C-107, C-108	206	-
C-109, C-110, C-111, C-112, C-113	375	-
E-103, E-106, E-109, E-112, E-115	-	54.2
Total	3.48E+05	54.2

EQUIPMENT LIST AND UNIT DESCRIPTIONS

All equipment in this chemical plant serves a specific and unique purpose, with the exception of duplicate equipment for modular design. Each piece of equipment is designed with either carbon or stainless steel, depending on the interacting chemicals, temperature, and pressure. Stainless steel is more resistive to corrosion and high temperatures, but carbon steel is more affordable if conditions allow.

The design team utilized centrifugal compressors as the compressor chosen for the entire process. Centrifugal compressors allow for the processing of large flow rates of gas required for the system. The centrifugal pumps also all had combustion engine drivers. This is to account for the large amount of shaft power needed to pressurize the nitrogen, hydrogen, and ammonia feed to their respective pressures.

The team also utilized modular design throughout the plant. The electrolyzers operate in parallel in order to create the required flow rate of hydrogen in the most cost effective way, without jeopardizing the purity. For the ammonia synthesis, the feed preparation took place with modular units in parallel. The five modules consisted of a propane compressor, an ammonia feed compressor, and two heat exchangers. The nitrogen pressure swing adsorbers were also designed in parallel. Using modular design, also allowed the team to use modular costing, as explained in the economics section.

A detailed description of each piece of equipment and its purpose is listed below in Table 12.

Table 12: Process Equipment List and Unit Descriptions

Process Equipment	Unit Description
C-101	Raise pressure of air to the requirement of PSA. Made of carbon steel.
ME-101	Remove water from air to avoid contamination of PSA process. Made of carbon steel.
CF-101	Remove molecules from air that cannot separate by PSA. Made of carbon steel, with activated carbon cartridges.
ABT-101	Remove water from air to avoid contamination of PSA process. Made of carbon steel.
T-101, T102	Separate nitrogen from air by pressure swing adsorption.
BV-101	Avoid vacuum if nitrogen production slows and to store extra nitrogen. Made of carbon steel.
V-101	Separate condensed ammonia from gaseous stream by pressure drop. Made of stainless steel.
E-102, E-105, E-108, E-111, E-114	Condense ammonia with use of propane as refrigerant. Made of stainless steel.
R-101	Pushes ammonia synthesis reaction to completion via catalyst, heat, and pressure. Made of stainless steel.
C-103	Raise pressure of hydrogen for ammonia synthesis. Made of carbon steel.
C-102	Raise pressure of nitrogen for ammonia synthesis. Made of carbon steel.
C-104, C-105, C-106, C-107, C-108	Raise pressure of mixture for ammonia synthesis. Made of stainless steel.
C-109, C-110, C-111, C-112, C-113	Raise the pressure of propane for the refrigeration cooler. Made of stainless steel.
E-103, E-106, E-109, E-112, E-115	Cool propane within the refrigeration cycle. Made of carbon steel.
E-101, E-104, E-107, E-110, E-113	Raise temperature of reactor inlet. Made of stainless steel.
EM-101, EM-102, EM-103, EM-104, EM-105, EM-106, EM-107, EM-108, EM-109, EM-110	Splits water molecules into pure hydrogen and pure oxygen streams. Made of stainless steel.
FWS-101	Water storage to prevent water disruption to electrolyzer modules. Made of carbon steel.
WP-101	Purifies water to proper purity for electrolysis. Made of carbon steel.

EQUIPMENT SPECIFICATION SHEETS

Table 13: Electrolyzer Spec Sheet

Equipment Name	Electrolyzer		
Item No.	EM-101, EM-102, EM-103, EM-104, EM-105, EM-106, EM-107, EM-108, EM-109, EM-110		
No. Required	10		
Function	Split water molecule into pure hydrogen and pure water		
Operation	Continuous flow		
Materials Handled (lb/hr)	Stream 4	Stream 14	Stream 24
Total	723	321	82
Hydrogen	-	-	82
Oxygen		321	
Water	723	-	-
Design Data			
Temperature (°F)	80	120	120
Pressure (psi)	14.7	480	480
Density (lb/ft^3)	62.81	2.6	0.16
Utilities	electricity		
Comments	MOC is stainless steel		

Table 14: Mist Eliminator Vessel Spec Sheet

Equipment Name	Mist Eliminator Vessel		
Item No.	V-102		
No. Required	1		
Function	Remove water from air to avoid contamination of PSA process		
Operation	Continuous flow		
Materials Handled (SCFH)	Stream 42	Stream 43	Stream 44
Total	18,000	4	17,160
Air	18,000	-	17,160
Water	-	4	-
Design Data			
Temperature (°F)	596	120	596
Pressure (psi)	100	14.7	100
Density (lb/ft³)	0.29	62.4	0.29
Utilities	None		
Comments	MOC is Carbon Steel		

Table 15: Carbon Filter Spec Sheet

Equipment Name	Carbon Filter	
Item No.	V-103	
No. Required	1	
Function	Remove molecules from air that cannot separate by PSA	
Operation	Continuous flow	
Materials Handled (SCFH)	Stream 44	Stream 45
Total	17,160	17,160
Air	17,160	17,160
Design Data		
Temperature (°F)	596	596
Pressure (psi)	100	100
Density (lb/ft³)	0.29	0.29
Utilities	None	
Comments	Carbon cartridge style filter	

Table 15: Air Buffer Tank Spec Sheet

Equipment Name	Air Buffer Tank		
Item No.	V-104		
No. Required	1		
Function	Remove water from air to avoid contamination of PSA process		
Operation	Continuous flow		
Materials Handled (SCFH)	Stream 45	Stream 46	Stream 47
Total	17,160	4	16,320
Air	17,160	-	16,320
Water	-	4	-
Design Data			
Temperature (°F)	596	120	596
Pressure (psi)	100	14.7	100
Density (lb/ft³)	0.29	62.4	0.29
Utilities	None		
Comments	MOC is Carbon Steel		

Table 16: Nitrogen Pressure Swing Adsorber Spec Sheet

Equipment Name	Nitrogen Pressure Swing Adsorber		
Item No.	T-101		
No. Required	2		
Function	Separate nitrogen from air by pressure swing adsorption		
Operation	Continuous flow		
Materials Handled (SCFH)	Stream 47	Stream 48	Stream 116
Total	16,320	96	1,200
Air	16,320	-	-
Nitrogen	-	96	-
Waste Gas	-	-	1,200
Design Data			
Temperature (°F)	596	77	77
Pressure (psi)	100	70	70
Density (lb/ft³)	0.29	1	0.82
Utilities	None		
Comments	MOC is Carbon Steel, contains 5A carbon molecular sieves as packing		

Table 17: Nitrogen Buffer Vessel Spec Sheet

Equipment Name	Nitrogen Buffer Vessel	
Item No.	V-105	
No. Required	1	
Function	Raise pressure of air to requirement of PSA	
Operation	Continuous flow	
Materials Handled (SCFH)	Stream 48	Stream 49
Total	96	96
Nitrogen	96	96
Design Data		
Temperature (°F)	77	77
Pressure (psi)	70	70
Density (lb/ft³)	1	1
Utilities	None	
Comments	MOC is Carbon Steel	

Table 18: Ammonia Separator Spec Sheet

Equipment Name	Ammonia Separator		
Item No.	V-106		
No. Required	1		
Function	Separate condensed ammonia from gaseous stream by pressure drop		
Operation	Continuous flow		
Materials Handled (lb/hr)	Stream 64, 76, 87, 98, 109	Stream 66, 77, 88, 99, 110	Stream 111
Total	3,614	2,694	920
Hydrogen	332	332	0
Ammonia	1,163	245	919
Nitrogen	2,119	2,118	1
Design Data			
Temperature (°F)	14	-5	-5
Pressure (psig)	1728	568	568
Density (lb/ft3)	4.714	1.27	41.06
Utilities	None		
Comments	MOC is stainless steel		

Table 19: Ammonia Reactor Spec Sheet

Equipment Name	Ammonia Reactor	
Item No.	R-101	
No. Required	1	
Function	Pushes reaction to completion via catalyst, heat, and pressure	
Operation	Continuous flow	
Materials Handled (lb/hr)	Stream 58, 73, 84, 95, 106	Stream 61, 74, 85, 96, 107
Total	3,614	2,694
Hydrogen	495	332
Ammonia	245	1,163
Nitrogen	2,874	2,119
Design Data		
Temperature (°F)	779	1250
Pressure (psi)	1738	1736
Density (lb/ft3)	1.274	1.091
Utilities	None	
Comments	MOC is stainless steel, AmoMax-10 Catalyst, plug flow reactor	

Table 20: Ammonia Storage Tank Spec Sheet

Equipment Name	Ammonia Storage Tank
Item No.	TK-101
No. Required	1
Function	Store liquid ammonia
Operation	Continuous flow
Materials Handled (lb/hr)	Stream 111
Total	920
Hydrogen	0
Ammonia	919
Nitrogen	1
Design Data	
Temperature (°F)	-5
Pressure (psi)	568
Density (lb/ft3)	41.06
Utilities	none
Comments	MOC is Stainless Steel

Table 21: Air Compressor Spec Sheet

Equipment Name	Air Compressor	
Item No.	C-101	
No. Required	1	
Function	Raise pressure of air to requirement of PSA	
Operation	Continuous flow	
Materials Handled (SCFH)	Stream 41	Stream 42
	70,000	18,000
Air	70,000	18,000
Design Data		
Temperature (°F)	70	596
Pressure (psi)	14.7	100
Density (lb/ft³)	0.075	0.29
Utilities	441 kWh for compressor and driver	
Comments	MOC is Carbon Steel, contains an internal combustion engine driver	

Table 22: Nitrogen Compressor Spec Sheet

Equipment Name	Nitrogen Compressor	
Item No.	C-102	
No. Required	1	
Function	Raise pressure of nitrogen for ammonia synthesis	
Operation	Continuous flow	
Materials Handled (lb/hr)	Stream 49	Stream 50
Total	3,785	3,785
Nitrogen	3,785	3,785
Design Data		
Temperature (°F)	77	596.7
Pressure (psi)	69.6	580.2
Density (lb/ft3)	0.411	1.449
Utilities	148 kWh for compressor and driver	
Comments	MOC is Carbon Steel	

Table 22: Hydrogen Compressor Spec Sheet

Equipment Name	Hydrogen Compressor	
Item No.	C-103	
No. Required	1	
Function	Raise pressure of hydrogen for ammonia synthesis	
Operation	Continuous flow	
Materials Handled (lb/hr)	Stream 34	Stream 35
Total	815	815
Hydrogen	815	815
Design Data		
Temperature (°F)	77	119.5
Pressure (psi)	464	6.89
Density (lb/ft3)	0.1656	0.1863
Utilities	38 kWh for compressor and driver	
Comments	MOC is carbon steel	

Table 23: Feed Compressor Spec Sheet

Equipment Name	Feed Compressor	
Item No.	C-104, C-105, C-106, C-107, C-108	
No. Required	5	
Function	Raise pressure of mixture for ammonia synthesis	
Operation	Continuous flow	
Materials Handled (lb/hr)	Stream 56, 71, 82, 93, 104	Stream 57, 72, 83, 94, 105
Total	3,614	3,614
Hydrogen	495	495
Ammonia	245	245
Nitrogen	2,874	2,874
Design Data		
Temperature (°F)	67.7	329.1
Pressure (psi)	568	1740
Density (lb/ft3)	1.021	1.992
Utilities	206 kWh for compressor and driver	
Comments	MOC is Stainless Steel	

Table 24: Refrigeration Compressor Spec Sheet

Equipment Name	Refrigeration Compressor	
Item No.	C-109, C-110, C-111, C-112, C-113	
No. Required	5	
Function	Raise pressure of air to requirement of PSA	
Operation	Continuous flow	
Materials Handled (lb/hr)	Stream 67, 78, 89, 100, 112	Stream 68, 79, 90, 101, 113
Total	24130	24130
Propane	24,130	24,130
Design Data		
Temperature (°F)	-0.4	154.8
Pressure (psi)	19.3	203.1
Density (lb/ft3)	0.3239	1.799
Utilities	375 kWh for compressor and driver	
Comments	MOC is Stainless Steel	

Table 25: Feed/Effluent Exchanger Spec Sheet

Equipment Name	Feed/Effluent Exchanger			
Item No.	E-101, E-104, E-107, E-110, E-113			
No. Required	5			
Function	Raise temperature of reactor inlet			
Operation	Continuous flow			
Materials Handled (lb/hr)	Stream 61, 74, 85, 96, 107	Stream 63, 75, 86, 97, 108	Stream 57, 72, 82, 94, 105	Stream 58, 73, 84, 95, 106
Total	3,614	3,614	3,614	3,614
Hydrogen	332	332	495	495
Ammonia	1,163	1,163	245	245
Nitrogen	2,119	2,119	2,874	2,874
Design Data				
Temperature (°F)	795.6	795.6	329.1	779
Pressure (psi)	1734	1734	1740	1738
Density (lb/ft3)	1.48	1.48	1.992	1.274
Utilities	none			
Comments	MOC is stainless steel			

Table 26: Ammonia Condenser Spec Sheet

Equipment Name	Ammonia Condenser			
Item No.	E-102, E-105, E-108, E-111, E-114			
No. Required	5			
Function	Condense Ammonia with use of propane as refrigerant			
Operation	Continuo us flow			
Materials Handled (lb/hr)	Stream 63, 75, 86, 97, 108	Stream 64, 76, 87, 98, 109	Stream 70, 81, 92, 103, 116	Stream 67, 78, 89, 100, 112
Total	3,614	3,614	24,130	24,130
Hydrogen	332	332	-	-
Ammonia	1,163	1,163	-	-
Nitrogen	2,119	2,119	-	-
Propane	-	-	24,130	24,130
Design Data				
Temperature (°F)	795.6	14	-4	-0.4
Pressure (psi)	1734	1728	20.7	19.3
Density (lb/ft3)	1.48	4.714	0.7914	0.3239
Utilities	Propane			
Comments	MOC is stainless steel			

Table 27: Refrigeration Cooler Spec Sheet

Equipment Name	Refrigeration Cooler	
Item No.	E-103, E-106, E-109, E-112, E-115	
No. Required	5	
Function	Cool propane within refrigeration cycle	
Operation	Continuous flow	
Materials Handled (lb/hr)	Stream 68, 79, 90, 101, 113	Stream 69, 80, 91, 102, 114
Total	24,130	24,130
Propane	24,130	24,130
Design Data		
Temperature (°F)	154.8	110.5
Pressure (psi)	203.1	201.6
Density (lb/ft3)	1.799	28.79
Utilities	Cooling Water	
Comments	MOC is Carbon Steel	

EQUIPMENT COST SUMMARY

To cost the equipment, heuristics and costing methods from *Analysis, Synthesis, and Design of Chemical Processes* by Turton et al. were used. The Chemical Engineering Cost Index (CEPCI) was used to escalate costs to the current year's dollar amount. All equations used for costing are explained and labelled in Appendix A. Costing takes into account the material of construction for each piece of equipment.

The process was also created utilizing modular costing techniques. When producing identical equipment a learning curve of approximately 20% can be assumed for each piece of subsequent equipment. This is larger than the learning curve of 10% for traditional stick built plants. Modular costing can be calculated using Equation 1 and Equation 2.

$$k_n = k_1 n^{\log_2 p}$$

Equation 1

$$K(N) = \sum_{1}^{N} k_n$$

Equation 2

Utilizing the above equations takes into account economies of mass achieved from production of similar pieces of equipment. This however, does decrease the economies of scale achieved from creating larger pieces of equipment. A summary of each piece of equipment can be found in Table 28.

Table 28: Equipment Cost Summary

Equipment	Cost (2020)
Hydrogen Production	**$1,880,000**
Electrolyzer (Purifier and Tank)	$1,800,000
K-103	$78,000
Nitrogen Production	**$1,560,000**
Pressure Swing Adsorber	$720,000
N2 Receiver	$26,400
AMP	$4,820
Air Compressor	$476,000
Compressor Driver	$160,000
Mist Eliminator	$4,450
Air Buffer Tank	$14,700
Carbon Filter	$987
K-102	$150,000
Ammonia Production	**$42,600,000**
K-101	$1,160,000
K-100	$835,000
PFR-100	$20,100,000
Storage Tank	$1,370,000
V-100	$18,900,000
Cooler	$133,000
E-100	$169,000
Wind Turbines	**$10,100,000**

FIXED CAPITAL INVESTMENT SUMMARY

The distribution of the equipment cost is shown below in Figure 9 while the best/worst scenarios and operating cost are found in the following tables.

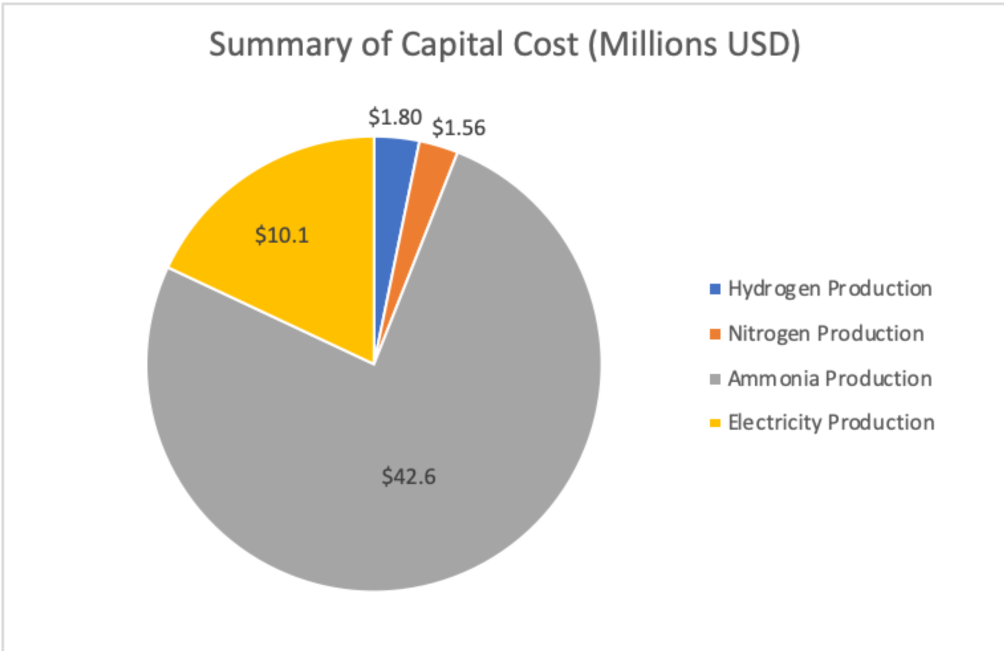


Figure 9: Equipment Cost Summary

Table 29: Net Present Value Best/Worst Case

Best Case	Worst Case
NPV	NPV
$59,700,000	$(17,250,000)

Table 30: Operating Costs

Fixed Capital Investment ($/yr)	N/A
Raw Materials Cost ($/yr)	$427
Utilities ($/yr)	$33,715
Direct Labor Cost ($/yr)	$898,560
Manufacturing Cost (COMd) ($/yr)	$303,112

SAFETY, HEALTH, AND ENVIRONMENTAL CONSIDERATIONS

The safety of the environment and plant personnel is of utmost importance when designing a chemical process. Proper OSHA and EPA guidelines have been followed to ensure compliance and risk minimization. Employees of the plant will be trained and educated on proper safety, chemical handling, and emergency procedures prior to starting work. All employees will wear fire retardant clothing, eye protection, gloves, and hard hats when working around process equipment [26]. Employees must also be trained in proper lock out, tag out procedures for maintenance requirements. Only personnel certified with hot work training, enclosed space training, or chemical handling skills will be allowed to perform those tasks.

The process has no waste streams. Low purity oxygen is able to be vented to the atmosphere from the adsorber and the ammonia process does not have waste due to the use of a recycle stream. However, loss of containment can pose serious risk to personnel and the environment as discussed in further sections.

PROCESS SAFETY CONSIDERATIONS

The safety and environmental concerns of the plant is the absolute utmost priority at all times. The plant operates with full compliance to the Occupational Safety and Health Administration's (OSHA) guidelines, as well as the Environmental Protection Agency's (EPA) environmental rules. All employees, operators, contractors, and visitors must observe all plant safety requirements. Anyone has the "stop work authority" allowing any unsafe action to be stopped, regardless of job title. Safety will be prioritized by all members of staff. The process plant is designed with inherent safety in mind as described in subsequent paragraphs.

High Pressure

High pressure is found all throughout the ammonia synthesis portion of the process. The discharge from C-102 onwards has high pressures upwards of 1700 psig. Both the separator and reactor are equipped with pressure relief systems. The valves associated with each piece of equipment release the high pressure vapor if either vessel is over pressurized. The vapors are sent to the overhead and back through the recycle stream to prevent atmospheric discharge. To ensure pressure is held constant, back pressure gas regulators are installed prior to both the reactor and separator. The valves hold the pressure within the vessels and release the downstream pressure once the setpoint is reached [11]. If the pressure exceeds the initial setpoint, the valve will release gas to the overhead to regulate the pressure upstream. To ensure proper functionality, inspections should be performed on all valves according to the specific manufactures' instructions and good engineering practices [10].

High Temperature

High temperatures are found throughout the process ranging from ~150-700°F with the highest being at the outlet of the ammonia synthesis reactor R-101. The temperature must be high in order for the ammonia synthesis reaction to occur. The reactor vessel with the highest temperature is due to the exothermic reaction taken place in the presence of catalyst. The reactor vessel and process lines from the inlet of the reactor to the outlet of the feed/effluent exchangers should be insulated to ensure temperature within the pipes are kept high enough for the reaction to take place and for safety purposes.

Low Temperature

Within the refrigeration cycle, propane is used to condense the gaseous ammonia. The propane and ammonia are cooled to temperatures as low as -5°F through both the refrigeration loop and after the pressure is dropped within the separator V-106.

Chemical Hazards

The potential hazards associated with each chemical utilized in the process is presented in Table 31. The hazards were taken from the Safety Data Sheet information from vendor resources and CAMEO Chemicals [13]. The opportunities to mitigate the hazards from these chemicals are also listed. This will allow for inherently safer design, and lower risk to chemical exposure.

Table 31: Chemical Hazard Summary

Material/Chemical	Hazards in SDS	Mitigation Steps
Ammonia [13]	Toxic to aquatic life, flammable in gaseous state, can lead to skin corrosion or extreme eye irritation and damage, harmful if inhaled, gas under pressure has potential to explode if heated.	Keep in a well-ventilated area, ensure any loss of containment is vented to overhead and back through recycle, wear protective gloves, clothing and eye/face protection, and keep away from ignition sources.
AmoMax-10 Catalyst	May cause serious eye irritation.	Eye and face protection must be worn at all times and skin it to be washed thoroughly after handling.
Carbon Molecular Sieve	May cause respiratory, skin and eye irritation. If inhaled, move the person to fresh air.	Contact will be limited to trained personnel only. Strict procedures will be created for changing of adsorber packing, in order to minimize exposure risk.
Hydrogen [13]	May displace oxygen resulting in dizziness or asphyxiation, gas under pressure may explode if heated, and extremely flammable.	Keep in well ventilated area away from heat source.

Nitrogen [13]	May displace oxygen resulting in dizziness or asphyxiation, gas under pressure may explode if heated, and extremely flammable.	Keep in well ventilated area away from heat source.
Potassium Hydroxide [13]	Can cause serious or permanent injury, corrosive to metals, noncombustible, reacts exothermically with acids.	Ensure proper maintenance of electrolyzers to check for corrosion and avoid loss of containment.
Propane [13]	May form explosive mixtures with air, gas under pressure may explode if heated, extremely flammable, liquid may cause burns close to that of frostbite, gas may displace oxygen resulting in dizziness or asphyxiation.	Keep in well ventilated area away from heat source, wear protective gloves when handling liquid.

Initial Interaction Matrix

In the event of loss of containment it is of the utmost importance to be prepared for the worst case scenario. All chemicals are evaluated based on their reactive hazards with other chemicals. The CAMEO Chemicals website used to create an initial interaction matrix for all chemical combinations [13]. The matrix includes every chemical present in the process. Even chemicals that are highly unlikely to ever come into contact are included for the utmost level of preparedness.

	Activated Carbon	Anhydrous Ammonia	Compressed Air	Hydrogen	Iron Oxide	Nitrogen	Oxygen	Potassium Hydroxide	Propane
Anhydrous Ammonia	Compatible No known hazards								
Compressed Air	Caution Exothermic	Compatible None							
Hydrogen	Compatible None	Compatible None	Caution Generates heat Unstable when heated May explode						
Iron Oxide	Compatible None	Compatible None	Incompatible Generates gas May over pressurize Exothermic May produce SO_2	Compatible None					
Nitrogen	Compatible None	Compatible None	Compatible None	Compatible None	Compatible None				
Oxygen	Caution Generates heat	Caution Generates gas May explode	Caution Potentially hazardous	Incompatible Explosive Flammable Generates gas Generates heat Unstable when heated May explode	Incompatible Flammable Generates gas Generates heat May explode Toxic May produce H_2S May produce SO_2	Compatible None			
Potassium Hydroxide	Compatible None	Caution Generates heat	Caution Potentially hazardous	Compatible None	Incompatible Corrosive Flammable Generates gas Generates heat May explode Toxic May produce H_2S	Compatible None	Incompatible Corrosive Generates gas Generates heat Toxic May produce acid fumes May produce NO		
Propane	Compatible None	Compatible None	Compatible None	Compatible None	Compatible None	Compatible None	Incompatible Flammable Generates gas Generates heat May explode Toxic May produce CO	Compatible None	
Water	Compatible None	Caution Generates heat	Compatible None	Compatible None	Incompatible Corrosive Flammable Generates gas Generates heat Toxic May produce H_2S	Compatible None	Incompatible Corrosive Generates gas Generates heat Toxic May produce acid fumes May produce NO	Incompatible Corrosive Generates gas Generates heat Toxic May produce base fumes	Compatible None

Figure 10: Interaction Matrix

Inventory Estimates of Chemicals

The inventory estimates are listed below in Table (XX). Most materials are only in pipes from their inlet to the plant until use in a reactor or electrolyzer. Most of the excess or byproduct material is either recycled, reacted, or sold off via pipeline, and therefore not stored on site. The only inventory to assess at that point is the material within the pipes, as well as ammonia, the AmoMax-10 catalyst, and propane. Each of these materials is hazardous and the ammonia plant is inherently safer by minimizing the amount of each on site. Only the required amount of propane for the reactor to operate for an hour, is stored on site. The catalyst is minimized from a cost and safety standpoint, and only two hour's worth of ammonia production is stored before it is transported off site. By minimizing the overall inventory on site, the plant is safer and more risk-averse. This decreases the likelihood of a catastrophic loss of containment.

Table 32: Inventory Update

Inventory Updates	Symbol	Amount (kg)	Amount (kg/day)
Ammonia	NH3	5,200	53,500
Nitrogen	N2	Flow rate to reactor	20,600
Oxygen	O2	Not Stored	34,900
Hydrogen	H2	Flow rate to reactor	8,820
Water	H2O	Not Stored	78,700
Propane	C3H8	Not Stored	11,200
Catalyst	AmoMax-10	Reactor volume	same
Potassium Hydroxide	KOH	54.4	54.4

The material properties for all chemicals are listed below in table X. The physical properties are important to understand which chemicals will flash upon loss of containment, and which are potential fire hazards. Knowing the chemical inventory will help clarify the consequences and series of procedures necessary to follow if an incident occurs.

Table 33: Material Properties

	Molecular Weight (lb/lbmole)	Normal Boiling Point (°F)	Flammability Limit	Flash Point (°F)
Ammonia	17	-28	15.2-27.4%	132
Nitrogen	28	-320	N/A	N/A
Oxygen	32	-297	N/A	N/A
Hydrogen	1	-423	4-76%	N/A
Potassium Hydroxide	56	2,408	N/A	N/A
Water	18	212	N/A	N/A
Propane	44	-43	1.8-8.4%	-155
AmoMax-10 Catalyst	N/A-	N/A	N/A	N/A
	Autoignition Temperature (°F)	**Liquid Density (lbm/ft^3)**	**Reactivity with Water**	**Toxicity Limit**
Ammonia	1204	38.6	No	4230 ppm/hr
Nitrogen	N/A	50.5	No	N/A
Oxygen	N/A	71.2	No	N/A
Hydrogen	932-1060	4.43	No	N/A
Potassium Hydroxide	N/A	132	Yes	Contact
Water	N/A	62.2	No	N/A
Propane	548	30.7	No	N/A
AmoMax-10 Catalyst	N/A	187	No	Inhalation

Potential Consequence Summary

All hazards for the process were considered and discussed by the design team. The hazards were analyzed based on their likelihood to cause equipment damage, break environmental compliance, cause loss of life, disrupt other business units, legal issues, or cause impact to the community. The risk of causing each incident was assessed in terms of low, medium, and high consequence. This allowed the team to create inherent safer designs to minimize the risk of high consequence hazards. Meanwhile, low consequence hazards were still addressed, but with less intense precautions. This allowed the design team to allocate money efficiently and train personnel for the most dangerous circumstances. For this table’s purpose, loss of containment (LOC) was the primary concern.

Table 34: Potential Consequence Summary

Hazard	Equipment Damage	Environmental Compliance	Loss of Life	Disruption of Other Business Units	Legal/PR	Community Impact
Ammonia Toxicity	Low	Low	Low	Low	Low	Low
Propane explosion	High	Low	Medium	Medium	High	Low
LOC (Ammonia)	Low	Medium	Low	Low	Low	Low
LOC (Propane)	Low	Medium	Medium	Low	Medium	Low
LOC (Hydrogen)	Low	Medium	Medium	Low	Low	Low
LOC (Nitrogen)	Low	Low	Low	Low	Low	Low

Existing Safeguards (Inherent Safety)

The process plant is designed with inherent safety in mind. Inherently safer processes and methods were used to reduce the risk before starting operation. Inherently safe processes are naturally risk-averse due to the consideration of safety prior to any human interaction. For instance, only one to two hours' worth of anhydrous ammonia product is stored in on site storage tanks at a time. This removes the risk associated with large amounts of product being stored in one location. By constantly having products transported, a large catastrophe can be avoided by not having too much flammable product near the plant. The team takes continuous efforts towards having a safe process plant and following all industry guideline.

Table 35: Hazard Summary

Hazard	Inherently Safer Concept	Incorporated Into Design
Large amounts of anhydrous ammonia on site	Minimization	Truck ammonia off-site every 1-2 hours in order to minimize the amount of ammonia at the plant.
Flaring off toxic/dangerous chemicals	Substitution	Use a recycle stream to process excess material rather than vent or flare it off.
Defective machinery	Substitution	The plant will be designed with stainless steel MOC where necessary.
Large amounts of propane on sight	Minimization	Only store one hour's worth of propane needed to operate the reactor.

OTHER IMPORTANT CONSIDERATIONS

Throughout the years, incidents within chemical plants have taken place and processes have been developed to decrease the number. A major contribution to the reduction in incident frequency is due to the Hazard and Operability (HAZOP) studies. This practice was incorporated into each piece of equipment design, material storage methods, and other aspects within the plant. Other relevant practices taken into consideration revolved primarily around a HAZOP analysis.

MANUFACTURING/OPERATION COSTS (EXCLUSIVE OF CAPITAL REQUIREMENTS)

Utility Costs

Utility costs for all portions of the plant are found in Table 36.

Table 36: Utility Cost

Mode	Cost
Cooling Water per Year	$428
Wind Turbine Maintenance per Year	$303,000

Raw Material Cost and Usage

Nitrogen production compresses outside air and has no raw material cost. Hydrogen production utilizes water and separates the oxygen from hydrogen – resulting in a water raw material cost. Ammonia synthesis uses the supplies materials from the prior processes. The raw material usage and cost is found in Table 37.

Table 37: Raw Material Cost and Usage

Raw Material	Amount Used (gal/day)	Price ($/1000 gal)
Water	20, 900	0.06

Table 38: Cash Flow Diagram

	0	1	2	3	4	5	6	7
End of Year	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Production (kg/yr)				9374952	18749904	18749904	18749904	18749904
x Sales Price, $/kg				0.75	0.75	0.75	0.75	0.75
Sales Revenue				$ 7,298,452	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905
+ Salvage Value								
- Royalties (basis)								
Net Revenue				$ 7,298,452	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905
- Manufacturing Costs				$ (617,907)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)
- Depreciation				$ (1,198,378)	$ (4,659,935)	$ (4,267,506)	$ (3,947,938)	$ (3,651,379)
- Amortization								
- Depletion								
- Loss Forward								
- Writeoff								
Taxable Income				$ 1,644,650	$ 8,701,156	$ 9,093,585	$ 9,413,153	$ 9,709,712
- Tax @ 40%				$ 411,163	$ 2,175,289	$ 2,273,396	$ 2,353,288	$ 2,427,428
Net Income				$ 1,233,488	$ 6,525,867	$ 6,820,189	$ 7,059,865	$ 7,282,284
+ Depreciation				$ 1,198,378	$ 4,659,935	$ 4,267,506	$ 3,947,938	$ 3,651,379
+ Amortization								
+ Depletion								
+ Loss Forward								
+ Writeoff								
- Building depreciation								
- Equipment								
-Working Capital								
-Fixed Capital	$ (63,913,518)							
-Vehicles								
Cash Flow	$ (63,913,518)			$ 2,431,866	$ 11,185,802	$ 11,087,695	$ 11,007,803	$ 10,933,663
Discount Factor (P/F)	1.00	0.93	0.86	0.79	0.74	0.68	0.63	0.58
Discounted Cash Flow	$ (63,913,518)			$ 1,930,494	$ 8,221,898	$ 7,546,099	$ 6,936,783	$ 6,379,687
NPV @ i*=	**$ 21,816,782**							
DFROR =	**3.66%**							

Table 38: Cash Flow Diagram Continued

8	9	10	11	12	13	14	15
2028	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
18749904	18749904	18749904	18749904	18749904	18749904	18749904	18749904
0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905
$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905
$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)
$ (3,377,829)	$ (3,124,093)	$ (2,890,169)	$ (2,851,821)	$ (2,851,182)	$ (2,851,821)	$ (2,851,182)	$ (2,851,821)
$ 9,983,261	$ 10,236,998	$ 10,470,922	$ 10,509,270	$ 10,509,909	$ 10,509,270	$ 10,509,909	$ 10,509,270
$ 2,495,815	$ 2,559,250	$ 2,617,730	$ 2,627,317	$ 2,627,477	$ 2,627,317	$ 2,627,477	$ 2,627,317
$ 7,487,446	$ 7,677,749	$ 7,853,191	$ 7,881,952	$ 7,882,432	$ 7,881,952	$ 7,882,432	$ 7,881,952
$ 3,377,829	$ 3,124,093	$ 2,890,169	$ 2,851,821	$ 2,851,182	$ 2,851,821	$ 2,851,182	$ 2,851,821
$ 10,865,275	$ 10,801,841	$ 10,743,360	$ 10,733,773	$ 10,733,614	$ 10,733,773	$ 10,733,614	$ 10,733,773
0.54	0.50	0.46	0.43	0.40	0.37	0.34	0.32
$ 5,870,170	$ 5,403,610	$ 4,976,255	$ 4,603,531	$ 4,262,466	$ 3,946,786	$ 3,654,377	$ 3,383,733

Table 38: Cash Flow Diagram Continued

16	17	18	19	20	21	22	23
2036	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**
18749904	18749904	18749904	18749904	18749904	18749904	18749904	9374952
0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 7,568,275
$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 14,596,905	$ 7,568,275
$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (1,235,814)	$ (617,907)
$ (2,851,182)	$ (2,851,821)	$ (2,851,182)	$ (2,851,821)	$ (2,851,182)	$ (2,851,821)	$ (2,851,182)	$ (712,955)
							$ (1,865,316)
$ 10,509,909	$ 10,509,270	$ 10,509,909	$ 10,509,270	$ 10,509,909	$ 10,509,270	$ 10,509,909	$ 4,372,097
$ 2,627,477	$ 2,627,317	$ 2,627,477	$ 2,627,317	$ 2,627,477	$ 2,627,317	$ 2,627,477	$ 1,093,024
$ 7,882,432	$ 7,881,952	$ 7,882,432	$ 7,881,952	$ 7,882,432	$ 7,881,952	$ 7,882,432	$ 3,279,072
$ 2,851,182	$ 2,851,821	$ 2,851,182	$ 2,851,821	$ 2,851,182	$ 2,851,821	$ 2,851,182	$ 712,955
							$ 1,865,316
$ 10,733,614	$ 10,733,773	$ 10,733,614	$ 10,733,773	$ 10,733,614	$ 10,733,773	$ 10,733,614	$ 5,857,344
0.29	0.27	0.25	0.23	0.21	0.20	0.18	0.17
$ 3,133,040	$ 2,901,006	$ 2,686,076	$ 2,487,145	$ 2,302,878	$ 2,132,326	$ 1,974,346	$ 997,595

ECONOMIC ANALYSIS

Capital Cost Estimates

Capital cost estimates and calculations were derived using vendor resources, peer-reviewed correlations, and *Analysis, Synthesis, and Design of Chemical Processes* [5]. The majority of equipment contains non-corrosive materials, so most equipment is designed as carbon steel. The plant is broken up into three different processes: hydrogen production, nitrogen production, and ammonia production. Multiple methods were used to gather information on the capital cost of equipment. Each process also optimized equipment. Each piece of equipment utilized calculations, heuristics or correlations from vendors and textbooks [5]. Listed below is the summary and explanation of each process within the design.

Table 39: Capital Cost Table

Equipment	Cost (2020)
Hydrogen Production	**$1,987,000**
Electrolyzer (Purifier and Tank)	$1,799,000
K-103	$189,000
Nitrogen Production	**$2,054,000**
Pressure Swing Adsorber	$720,000
N2 Receiver	$26,400
AMP	$4,820
Air Compressor	$478,000
Compressor Driver	$160,000
Mist Eliminator	$4,450
Air Buffer Tank	$14,700
Carbon Filter	$987
K-102	$647,000
Ammonia Production	**$42,600,000**
K-101	$1,160,000
K-100	$835,000
PFR-100	$20,100,000
Storage Tank	$1,370,000
V-100	$18,900,000
Cooler	$133,000
E-100	$169,000
Wind Turbines	**$10,100,000**

Note that Table 39 is referring to the unit cost of each item. Since the plant is modular, each additional unit is incrementally cheaper than the one prior. This is due to economies of mass and the use of a 20% learning curve.

For hydrogen production, each electrolyzer was priced using a correlation [18].. Each module cost is $250,000, and decreases incrementally for each additional module. This form of correlation helped substantially with the overall cost of the process plant.

The nitrogen costing was based substantially on vendor quotes, as the majority of the process relied on pressure swing adsorption. Pressure swing adsorption required more proprietary information that would otherwise be next to impossible to estimate the capital cost for. Most of the equipment, aside from the compressor and tanks, was calculated using OnSiteGas vendor pricing. The compressor and tanks' capital costs were estimated using *Analysis, Synthesis, and Design of Chemical Processes* [5]. Because nitrogen is inert, all equipment is carbon steel in order to minimize capital costs, while maintaining structural integrity of equipment.

For the cost of production and storage equipment for ammonia material, the *Analysis, Synthesis, and Design of Chemical Processes* [5] was used. The reactor catalyst was priced using vendor specifications [25]. Due to ammonia's lack of reactivity, carbon steel would provide ample structural integrity throughout the process. Without the ability to use carbon steel, the reactor and separator capital costs would be more than three times their carbon steel cost. The ammonia process is designed as modular in order to reduce the overall capital cost. The process consists of five unit modules, all working in parallel. All of the equipment from Table 39 is part of the module except for the ammonia reactor and separator. The ammonia module is sized to produce about 10.6 metric tones per day.

One of the greatest operating costs for this process is the electricity. In order to avoid this large operating cost, an onsite wind turbine farm was designed. Since the process plant will be built in the Minnesota River Valley, to utilize stranded wind energy. By utilizing wind turbines, the capital cost of the process increased, but the operating cost significantly decreased. The use of wind power also decreased the plant's carbon footprint. Each turbine costs $1,000,000 and produces roughly 1 MW of electricity [27]. The plant operates at 18.4 MW, requiring at least 19 turbines. Using a similar module cost correlation and running the turbines in parallel, $10.1MM is required for investment. This completely removes the cost of electricity, with the exception of yearly wind turbine maintenance. This decreases the plant operating cost by almost $9MM per year. This decision greatly impacted plant economics.

Revenue Estimates

Producing ammonia at 50 metric tones per day and attempting to make the design as profitable and economically attractive as possible while maintaining the importance of environmental concerns proved to be difficult. The price of ammonia is $680 per US ton, equivalent to just under $0.75 per kilogram. This value is an average of ammonia costs in the US

Midwest. Using an average price should prove to be more consistent with the average price over the next 20 years.

Another source of revenue is selling the excess oxygen from the hydrogen production process. Because of the large excess, it is to be transported via pipeline for better use, which benefits the plant both financially and environmentally.

Table 40: Revenue Summary

Type	Production (kg/day)	Revenue
Oxygen Sales ($40/ton)	53,500	$14,100,000
Ammonia Sales ($680/ton)	33,500	$540,000

Operating Cost Estimates

Ammonia production has a large operating cost range. Few raw materials are required, however, the amount of electricity required to operate the process is astronomical. Initially electricity was purchased from a local wind farm in Minnesota to help be environmentally friendly. The initial cost of electricity was $0.064 USD, totaling nearly $9 million a year. By investing more capital initially, for a smaller operating cost, the plant became economically profitable. The cost for the necessary power output of 19 MW is $10.1 million, with the only operating cost being wind turbine maintenance. The maintenance is ~3% of capital cost investment each year.

Water for the cooling of hydrogen production is also needed. Large amounts of water for both of these processes are needed [5].

Plant operators are the last annual operating cost and were calculated in accordance with the methods used in *Analysis, Synthesis, and Design of Chemical Processes* [5]. For the plant, 16 pieces of equipment required operator control, leading to 15 total operators per shift. A wage per operator of $30/hour was selected to correlate to industry standards.

Table 41: Operating Labor Costs

N_{np}	16
N_{OL}	3.2
Total Operators	15
Wagers ($/hr)	30
Annual OL Cost ($/yr)	899,000

Table 42: Operating Costs Summary

Utility	Cost
Turbine Maintenance	$ 303,000
Water	$ 34,000
Operating Labor	$ 899,000
Total	$1,240,000

DCFROR Analysis

Discounted Cash Flow Rate of Return analysis is used to evaluate the predicted economic success of a project. By discounting the cash flow diagram with respect to each year, using a minimum hurdle rate of 8%, the DCFROR is calculated. Similarly, calculating a net present value (NPV) for the project can indicate whether or not the project will be economically attractive or not.

As mentioned earlier because ammonia has a low sales value, but is expensive to produce, the profit margin is slim. Additionally, due to the efforts of the team to produce ammonia in an environmentally friendly manner, the capital investment was increased significantly. The Haber-Bosch process also operates at large pressures (~1740 psig), increasing cost estimates for tanks and reactors in order to safely accommodate the process. This is all taken into account in Table 43.

Table 43: Economic Analysis

DCFROR	3.66%
NPV	$21,800,000

Using the DCFROR analysis alone is not always the best metric for project success. Another metric frequently used in economic analysis is payback period, or the time it takes to breakeven. The payback period is roughly 14.06 years for this project. The goal of creating a modular and environmentally friendly ammonia plant was met. However, the NPV and ROR were not above the hurdle rate.

With more accurate sales prices, information in regards to future tax breaks and incentives for environmentally friendly plants, the economic goal may be achieved. To overcome the hurdle rate in the future, the capital costs should be decreased by altering the overall process and potentially decreasing the reactor and separator costs.

CASH FLOW DIAGRAMS

Sensitivity Analysis

To fully understand the economic analysis of the project and how heavily each variable weighs when determining the best design, a thorough sensitivity analysis was performed. The team evaluated capital cost, revenue, operating cost/utilities, and the amount of electricity required to operate the plant. With the amount of electricity changing, this caused the capital cost to change due to the number of wind turbines to operate the plant and operating cost required to keep the wind turbines operating.

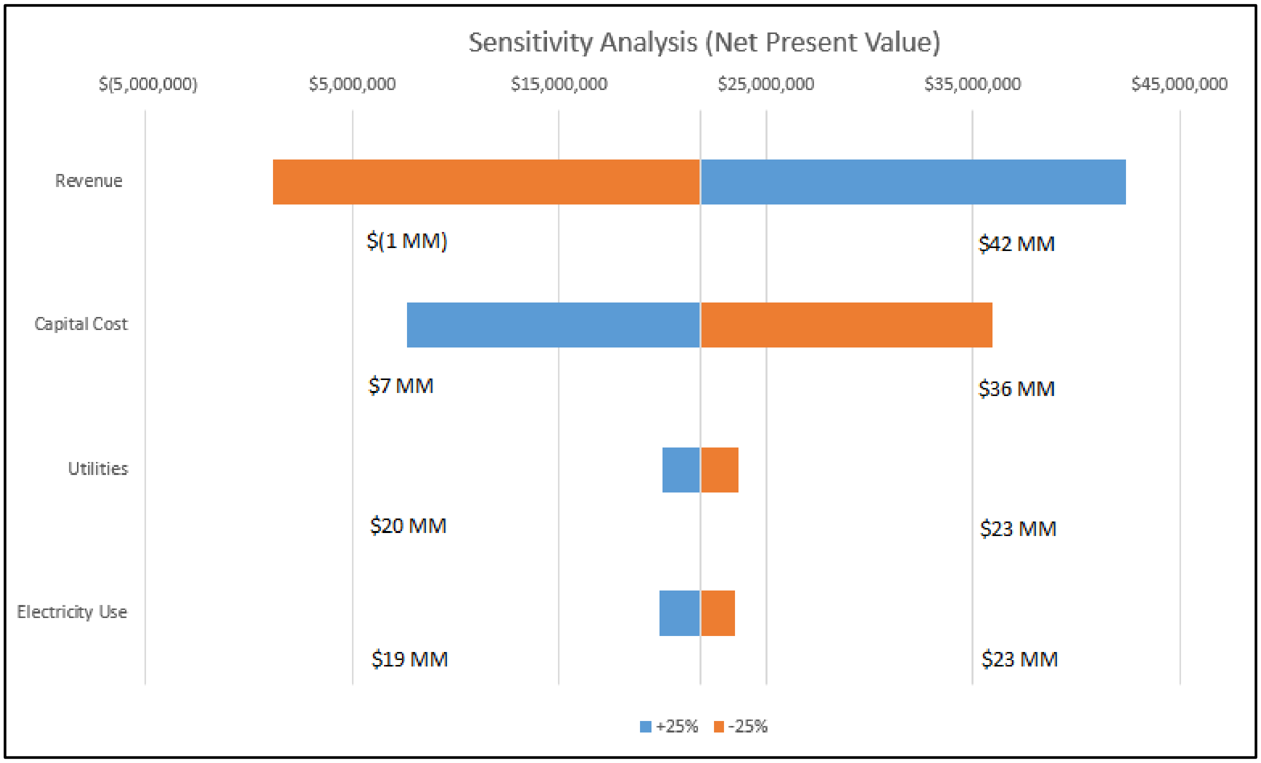


Figure 11: Sensitivity Analysis

From the sensitivity analysis, the variables that require the most attention from an economic value perspective can be addressed. Unsurprisingly, changes in revenue clearly lead to the largest range in the NPV. With continuous production rate and a lack of control of the sales price of ammonia, the revenue cannot be adjusted much within the project. This is not a huge concern due to the washout assumption, allowing for product price fluctuations. The capital cost depends on sizing, materials of construction, and what sort of modular facility the team decides. Based on these abilities, the capital cost can be decreased. Utilities and electricity use are both less volatile compared to the revenue and capital cost variables. Consequently, each variable will be adjusted, but the majority of future design work for this project will be either focusing on how to get more revenue through production rates or decreasing expenses when estimating capital costs.

Table 44: Sensitivity Analysis

	NPV	ROR
Best Case	$ 59,700,000	11.97%
Worst Case	$ (17,250,000)	-2.58%

Lastly, combining the results of the sensitivity analysis, the best and worst case economic scenarios were predicted. This Increased the revenue by 25% while decreasing the electricity, operating, and capital costs to create a net present value of 11.97%. These values indicate that the project would be well above the benchmark of being economically attractive. In contrast, the worst case scenario would drop the rate of return just below the viable limit, causing the project to be unprofitable. In conclusion, the range of net present value for the project is vast, but within reach of being profitable.

CONCLUSIONS

The study addressed the option to change the current ammonia supply chain by designing a clean, modular ammonia plant capable of producing 53 mtpd in the Minnesota River Valley instead of an ammonia production facility off the Gulf Coast. The design was simulated in Aspen HYSYS and then examined for technical feasibility. The process equipment specifications that were unable to be designed in Aspen HYSYS were specified by vendors. The economic attractiveness of the project can be visualized by a high DCFROR and NPV. A short payback period is preferred. The option outlined borders on the criteria listed.

The option is somewhat profitable. The project has annual revenue of $14.6 million with a 20-year useful plant life and minimum acceptable rate of return of 8%. The NPV of the project is $21.8 million with a DCFROR of 3.66%. The process is economically attractive but not viable under current circumstances.

RECCOMMENDATIONS

- Further advancements in carbon free technology needs to be more inexpensive before an economically feasible carbon free ammonia plant can be developed.
- An extremely small scale process could prove economically attractive for farmers. The decrease in plant size decreases capital and operating costs
- If the process does move forward to the construction phase, acquisition of a wind farm is essential to decreasing the overall electricity cost needed by the electrolysis of water

ACKNOWLEDGEMENTS

We would like to acknowledge the vendors who assisted with quotes and knowledge regarding some of the design processes. Special thanks to On Site Gas, specifically Micheal Montesi, for providing the team with valuable input on their Nitrogen separation processes. Their expertise allowed us to pick the most cost effective, and technically feasible method of nitrogen separation.

A thank you is also needed for William Handel of Clariant for being instrumental in choosing the best and most effective catalyst for the final anhydrous ammonia reaction within the Haber-Bosch process.

BIBLIOGRAPHY

1. "Global Agriculture Towards 2050." *Food and Agriculture Organization of the United Nations*, 2009, www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf.
2. "Ammonia Market Size & Outlook: Industry Forecast Report, 2014-2025." *Ammonia Market Size & Outlook | Industry Forecast Report, 2014-2025*, Oct. 2017, www.grandviewresearch.com/industry-analysis/ammonia-market.
3. "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *Where Wind Power Is Harnessed - U.S. Energy Information Administration (EIA)*, Apr. 2019, www.eia.gov/energyexplained/wind/where-wind-power-is-harnessed.php.
4. Briney, Amanda. "How Mass Production of Plant Fertilizers Increased World Population." *ThoughtCo*, ThoughtCo, 10 Apr. 2019, www.thoughtco.com/overview-of-the-haber-bosch-process-1434563.
5. Turton, Richard, et al. *Analysis, Synthesis, and Design of Chemical Processes*. Prentice Hall, 2018.
6. Buchanan, Eric, et al. "Performance of a Small-Scale Haber Process." *I&EC Research. 2016,* 55, 3742-3750.
7. Cussler, E.L., et al. "Modeling and Optimal Design of Absorbent Enhanced Ammonia Synthesis." *Processes, 2018,* 6, 91.
8. Converse, Alvin O. "Optimal Thermal Design of an Autothermal Ammonia Synthesis Reactor." *Ind. Eng. Chem. 1970, 4.*
9. *"Module 99: Propane as a Refrigerant for Use in Chillers for Air Conditioning Applications." CIBSE Journal, www.cibsejournal.com/cpd/modules/2016-09-fgas/.*
10. *"UNITED STATES DEPARTMENT OF LABOR." Process Safety Management | Occupational Safety and Health Administration, www.osha.gov/Publications/osha3132.html#mi.*
11. *Port, Jeff PortJeff. "What Is a Back Pressure Valve (or Regulator)?" Kimray Blog, 23 Jan. 2020, blog.kimray.com/what-is-a-back-pressure-valve-regulator/.*
12. "Ammonia." *National Center for Biotechnology Information. PubChem Compound Database*, U.S. National Library of Medicine, pubchem.ncbi.nlm.nih.gov/compound/Ammonia.

13. NOAA Office of Response. “Report: CAMEO Chemicals.” *NOAA*, cameochemicals.noaa.gov/report.
14. Llc. “Overall Heat Transfer Coefficient Table Charts and Equation.” *Engineers Edge*, www.engineersedge.com/thermodynamics/overall_heat_transfer-table.htm.
15. “WeatherSpark.com.” *Average Weather in Two Harbors, Minnesota, United States, Year Round - Weather Spark*, weatherspark.com/y/11612/Average-Weather-in-Two-Harbors-Minnesota-United-States-Year-Round.
16. *Manufacturers, Suppliers, Exporters & Importers from the World's Largest Online B2B Marketplace-Alibaba.com*, www.alibaba.com/product-detail/99-9-High-Purity-Propane-Refrigerant_62257510092.html?spm=a2700.7724857.normalList.47.15e320a8IJ7i1V.
17. “Hydrogen Production by Water Splitting Using Mixed Ionic-Electronic Conducting Membranes.” *ECS Meeting Abstracts*, 2007, doi:10.1149/ma2007-01/5/364.
18. None. “Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis.” Jan. 2009, doi:10.2172/1218930.
19. “Alkaline Water Electrolysis.” *Alkaline Water Electrolysis - an Overview | ScienceDirect Topics*, www.sciencedirect.com/topics/engineering/alkaline-water-electrolysis.
20. Chong, K C, et al. “RECENT PROGRESS OF OXYGEN/NITROGEN SEPARATION USING MEMBRANE TECHNOLOGY.” Journal of Engineering Science and Technology, vol. 11, no. 7, ser. 2016, 2016, pp. 1016–1030. 2016, doi:http://jestec.taylors.edu.my/Vol%2011%20issue%207%20July%202016/11_7_8.pdf <https://www.google.com/url?q=http://jestec.taylors.edu.my/Vol%252011%2520issue%25207%2520July%25202016/11_7_8.pdf&sa=D&ust=1585845436647000&usg=AFQjCNGOPnPLxM-fHuPAlTJrvR-tvt5IHA>.
21. Ivanova, Svetlana, and Robert Lewis. “Producing Nitrogen via Pressure Swing Adsorption Article.” Scribd, Scribd, June 2012, www.scribd.com/document/244294032/Producing-Nitrogen-via-Pressure-Swing-Adsorption-Article
22. “Methane Steam Reforming.” *Methane Steam Reforming - an Overview | ScienceDirect Topics*, www.sciencedirect.com/topics/engineering/methane-steam-reforming.
23. Balat, Havva, and Elif Kırtay. “Hydrogen from Biomass – Present Scenario and Future Prospects.” *International Journal of Hydrogen Energy*, vol. 35, no. 14, 2010, pp. 7416–7426., doi:10.1016/j.ijhydene.2010.04.137.
24. “Water.” *Water*, National Institute of Standards and Technology, webbook.nist.gov/cgi/cbook.cgi?ID=C7732185&Mask=2.
25. Clariant Ltd. “AmoMax® 10.” Clariant Ltd., 8 Nov. 2019, www.clariant.com/en/Solutions/Products/2014/07/22/10/58/AMOMAX10
26. “Using Agricultural Anhydrous Ammonia Safely.” *NASD*, nasdonline.org/1085/d000875/using-agricultAllural-anhydrous-ammonia-safely.html.
27. Rinkesh. “Wind Energy Cost.” Conserve Energy Future, 25 Dec. 2016, www.conserve-energy-future.com/windenergycost.php

APPENDIX

Appendix A: Equations

Heat Exchangers Calculations

When,

$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$$\text{LMTD} = \text{Log Mean Temperature Difference}$$
$$\Delta T_1 = \text{Hot}_{in} - \text{Cold}_{out}$$
$$\Delta T_2 = \text{Hot}_{out} - \text{Cold}_{in}$$

When,

$$Q = U_o A F \text{LMTD}$$

$$Q = \text{Heat Duty}$$
$$F = \text{LMTD Correction Factor}$$

Cooler	
LMTD (°F)	212.71
Uo (Btu/hr.ft2.°F)	150
Area (ft2)	75.01
Propane in (°F)	-4
Propane Out (°F)	-0.4
Process in (°F)	833.5
Process out (°F)	14
Design Pressure (psi)	1740
Flow (Btu/hr)	2393195
F	0.91

Condenser-2	
LMTD (°F)	39.96
Uo (Btu/hr.ft2.°F)	500

Area (ft2)	180.16
Water In (°F)	77
Water Out (°F)	107.6
Propane in (°F)	154.832
Propane Out (°F)	110.48
Design Pressure (psi)	203
Flow (Btu/hr)	3599744.4
F	0.91

E-100	
LMTD (°F)	469.33
Uo (Btu/hr.ft2.°F)	70
Area (ft2)	31.59
Feed In (°F)	365.9
Feed Out (°F)	779
Effluent in (°F)	1250.06
Effluent Out (°F)	833.5
Design Pressure (psi)	1740
Flow (Btu/hr)	1037841
F	0.91

8.4.7 Vessels

When,

$$\mathbf{V = 2Q5_{min}}$$

When,

$$\mathbf{V = \ Volume\ of\ Condensate\ Receiver}$$

$$\mathbf{Q = \ Volumetric\ Flow}$$

Ammonia Reactor	
Flow (SCFH)	889.4525
Volume (ft3)	147.41

Separator	
Flow (SCFH)	746.0325
Volume (ft3)	123.64

8.4.13 Costing Correlations

8.4.13.1 Vessels

When,

$$\log\left(C_p^o\right) = K_1 + K_2 \log(A) + K_3[\log(A)]^2$$

$$C_p^0 = \text{Cost, 2001 (\$)}$$
$$\text{K Constants} = \text{Table A.1 [book reference]}$$
$$A = \text{Size (Volume)}$$

When,

$$F_{p,vessel} = \frac{\frac{(P+1)D}{2[850 - .6(P+1)]} + 0.00315}{0.0063}$$

$$D = \text{Vessel Diameter}$$
$$F_{p,vessel} = \text{Vessel Pressure Factor}$$
$$P = \text{Design Pressure (barg)}$$

When,

$$C_{p,2001} = C_p^o F_p F_m$$

$$C_{p,2019} = C_{p,2001} \frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{p,2001} = \text{Purchase Cost, 2001}$$
$$C_{p,2019} = \text{Purchase Cost, 2019}$$
$$CEPCI_{2001} = 397$$
$$CEPCI_{2019} = 604.6$$
$$CEPCI = \text{Chemical Engineering Plant Cost Index [book reference]}$$

When,

$$C_{BM} = C_p^o(B_1 + B_2 F_m F_p)$$

$$C_{BM,2019} = C_{BM,2001} \frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{BM} = \text{Installed Cost, 2001}$$
$$C_{BM,2019} = \text{Installed Cost, 2019}$$
$$F_m = \text{Material Factor, Table A.18 [book reference]}$$
$$\text{B Constants} = \text{Table A.4 [book reference]}$$

8.4.13.2 Heat Exchangers/Pumps

When,

$$\log\left(C_p^o\right) = K_1 + K_2 \log(A) + K_3[\log(A)]^2$$

$$C_p^0 = \text{Cost, 2001 (\$)}$$
$$\text{K Constants} = \text{Table A. 1 [book reference]}$$
$$A = \text{Size (Area/Power)}$$

When,

$$\log\left(F_p\right) = C_1 + C_2 \log(P) + C_3[\log(P)]^2$$

$$F_p = \text{Pressure Factor}$$
$$\text{C Constants} = \text{Table A. 2 [book reference]}$$
$$P = \text{Design Pressure (barg)}$$

When,

$$C_{p,2001} = C_p^o F_p F_m$$

$$C_{p,2019} = C_{p,2001} \frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{p,2001} = \text{Purchase Cost, 2001}$$
$$C_{p,2019} = \text{Purchase Cost, 2019}$$
$$CEPCI_{2001} = 397$$
$$CEPCI_{2019} = 604.6$$
$$CEPCI = \text{Chemical Engineering Plant Cost Index [book reference]}$$

When,

$$C_{BM} = C_p^o(B_1 + B_2 F_m F_p)$$

$$C_{BM,2019} = C_{BM,2001} \frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{BM} = \text{Installed Cost, 2001}$$
$$C_{BM,2019} = \text{Installed Cost, 2019}$$
$$F_m = \text{Material Factor, Table A. 18 [book reference]}$$
$$\text{B Constants} = \text{Table A. 4 [book reference]}$$

8.4.13.2 Compressors

When,

$$log\left(C_p^o\right) = K_1 + K_2 log\,(A) + K_3[log\,(A)]^2$$

$$C_p^0 = Cost, 2001\ (\$)$$
$$K\ Constants = Table\ A.1\ [book\ reference]$$
$$A = Size\ (Area/Power)$$

When,

$$log\left(F_p\right) = C_1 + C_2 log\,(P) + C_3[log\,(P)]^2$$

$$F_p = Pressure\ Factor$$
$$C\ Constants = Table\ A.2\ [book\ reference]$$
$$P = Design\ Pressure\ (barg)$$

When,

$$C_{p,2001} = C_p^o F_p F_m$$

$$C_{p,2019} = C_{p,2001}\frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{p,2001} = Purchase\ Cost, 2001$$
$$C_{p,2019} = Purchase\ Cost, 2019$$
$$CEPCI\ _{2001} = 397$$
$$CEPCI_{2019} = 604.6$$
$$CEPCI = Chemical\ Engineering\ Plant\ Cost\ Index\ [book\ reference]$$

When,

$$C_{BM} = c_p^o F_M$$

$$C_{BM,2019} = C_{BM,2001}\frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{BM} = Installed\ Cost, 2001$$
$$C_{BM,2019} = Installed\ Cost, 2019$$
$$F_m = Material\ Factor, Table\ A.18\ [book\ reference]$$
$$B\ Constants = Table\ A.4\ [book\ reference]$$

C-101	
Power (kW)	205.9
Cpo	$77,169
Fp	1
Cp - 2001	$439, 865
Cp - 2020	$669,880
Cbm - 2001	$439, 865
Cbm - 2019	$669,880
K1	2.2897
K2	1.3604
K3	-0.1027
C1	0
C2	0
C3	0
Design Pressure (barg)	120
Fm	5.7
CEPCI - 2001	397
CEPCI - 2020	604.6
efficiency	75%

C-102	
Power (kW)	372.9
Cpo	$128,508
Fp	1
Cp - 2001	$732,496
Cp - 2020	$669,880
Cbm - 2001	$732,496
Cbm - 2019	$669,880
K1	2.2897
K2	1.3604
K3	-0.1027
C1	0

C2	0
C3	0
Design Pressure (barg)	14
Fm	5.7
CEPCI - 2001	397
CEPCI - 2020	604.6
efficiency	75%

C-103	
Power (kW)	8.3
Cpo	$2,840
Fp	1
Cp - 2001	$16,186
Cp - 2020	$24,650
Cbm - 2001	$16,186
Cbm - 2019	$24,650
K1	2.2897
K2	1.3604
K3	-0.1027
C1	0
C2	0
C3	0
Design Pressure (barg)	40
Fm	5.7
CEPCI - 2001	397
CEPCI - 2020	604.6
efficiency	75%

8.4.13.2 Drivers

When,

$$log\left(C_p^o\right) = K_1 + K_2 log\,(A) + K_3[log\,(A)]^2$$

$$C_p^0 = Cost, 2001\ (\$)$$
$$K\ Constants = Table\ A.1\ [book\ reference]$$
$$A = Size\ (Area/Power)$$

When,

$$log\left(F_p\right) = C_1 + C_2 log\,(P) + C_3[log\,(P)]^2$$

$$F_p = Pressure\ Factor$$
$$C\ Constants = Table\ A.2\ [book\ reference]$$
$$P = Design\ Pressure\ (barg)$$

When,

$$C_{p,2001} = C_p^o F_p F_m$$

$$C_{p,2019} = C_{p,2001}\frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{p,2001} = Purchase\ Cost, 2001$$
$$C_{p,2019} = Purchase\ Cost, 2019$$
$$CEPCI_{2001} = 397$$
$$CEPCI_{2019} = 604.6$$
$$CEPCI = Chemical\ Engineering\ Plant\ Cost\ Index\ [book\ reference]$$

When,

$$C_{BM} = C_p^o F_M$$

$$C_{BM,2019} = C_{BM,2001}\frac{CEPCI_{2001}}{CEPCI_{2019}}$$

$$C_{BM} = Installed\ Cost, 2001$$
$$C_{BM,2019} = Installed\ Cost, 2019$$
$$F_m = Material\ Factor, Table\ A.18\ [book\ reference]$$
$$B\ Constants = Table\ A.4\ [book\ reference]$$

C-101 Driver	
Power (kW)	252
Cpo	$67,770
Fp	1
Cp - 2001	$108,433
Cp - 2020	$165,135
Cbm - 2001	$108,433
Cbm - 2020	$165,135
K1	2.4604
K2	1.4191
K3	-0.1798
C1	0
C2	0
C3	0
Fm	1.6
CEPCI - 2001	397
CEPCI - 2020	604.4
efficiency	75%

C-102 Driver	
Power (kW)	550
Cpo	$99,533
Fp	1.6
Cp - 2001	$66,494
Cp - 2020	$101,265
Cbm - 2001	$66,494
Cbm - 2020	$101,265
K1	2.4604
K2	1.4191
K3	-0.1798
C1	0
C2	0

C3	0
Fm	1.6
CEPCI - 2001	397
CEPCI - 2020	604.4
efficiency	75%

C-103 Driver	
Power (kW)	45
Cpo	$19,979
Fp	1
Cp - 2001	$31,966
Cp - 2020	$48,682
Cbm - 2001	$31,966
Cbm - 2020	$48,682
K1	2.4604
K2	1.4191
K3	-0.1798
C1	0
C2	0
C3	0
Fm	1.6
CEPCI - 2001	397
CEPCI - 2020	604.4
efficiency	75%

C-104 Driver	
Power (kW)	15
Cpo	$6,150
Fp	1
Cp - 2001	$35,055
Cp - 2020	$53,387
Cbm - 2001	$35,055
Cbm - 2020	$53,387
K1	2.4604
K2	1.4191
K3	-0.1798
C1	0
C2	0
C3	0

Fm	1.6
CEPCI - 2001	397
CEPCI - 2020	604.4
efficiency	75%

8.4.14 Operating Labor

When,

$$N_{OL} = \left(6.29 + 31.7P^2 + 0.23N_{np}\right)^{0.5}$$

$$N_{np} = \sum \text{Equipment}$$

When,

$$N_{OL} = \text{Number of Operators/Shift}$$
$$P = 0$$

Appendix B: Vendor Information

Adsorber Quote

Michael Montesi
Sales Manager-Commercial Products
On Site Gas Systems, Inc.
35 Budney Rd.
Newington, CT 06111
Phone: 860-667-8888 Ext: 230
http://www.onsitegas.com/

An ISO 9001:2015 / ISO 13485:2016 Certified C

Catalyst

Bill Handel
Sales Account Manager - Syngas Catalysts, Americas
BU Catalysts

Clariant Corporation | 1600 West Hill Street | Louisville, KY
Phone: +1 502 634 7079 | Fax: +1 502 637 3732 | Mobile: +1
www.clariant.com

Appendix C Ammonia Synthesis Calculations

Ammonia Condenser	
LMTD (°F)	212.71
Uo (Btu/hr.ft2.°F)	150
Area (ft2)	75.01
Propane in (°F)	-4
Propane Out (°F)	-0.4
Process in (°F)	833.5
Process out (°F)	14
Design Pressure (psi)	1740
Flow (Btu/hr)	2393195
Material of Construction	Stainless Steel
F	0.91

Refrigeration Cooler	
LMTD (°F)	39.96
Uo (Btu/hr.ft2.°F)	500
Area (ft2)	180.16
Water In (°F)	77
Water Out (°F)	107.6
Propane in (°F)	154.832
Propane Out (°F)	110.48
Design Pressure (psi)	203
Flow (Btu/hr)	3599744.4
Material of Construction	Stainless Steel
F	0.91

Feed/Effluent Exchanger	
LMTD (°F)	469.33
Uo (Btu/hr.ft2.°F)	70
Area (ft2)	31.59
Feed In (°F)	365.9
Feed Out (°F)	779
Effluent in (°F)	1250.06
Effluent Out (°F)	833.5
Design Pressure (psi)	1740
Flow (Btu/hr)	1037841
Material of Construction	Stainless Steel
F	0.91

Reactor		
Calculations		
Q	0.42	m3/min
V	4.18	m3
*volume at 5 minutes		
Separator		
Calculations		
Q	0.35	m3/min
V	3.50	m3
*volume at 5 minutes		

Ammonia Reactor	
Flow (SCFH)	889.4525
Inlet Pressure (psi)	1740
Outlet Pressure (psi)	1738.55
Inlet Temperature (°F)	779
Outlet Temperature (°F)	1250
Volume (ft3)	147.41
Reaction Rate of Conversion	26.28%

Separator	
Flow (SCFH)	746.0325
Inlet Pressure (psig)	1728
Outlet Pressure (psig)	568
Inlet Temperature (°F)	14
Outlet Temperature (°F)	-5.031
Volume (ft3)	123.64

Feed Compressor	
Power (kW)	205.9
Suction Pressure (psi)	71.05
Discharge Pressure (psi)	1740
Inlet Temperature (°F)	92.86
Outlet Temperature (°F)	365.9
Material of Construction	Stainless Steel
Driver (hp)	500
Refrigeration Compressor	

Power (kW)	372.9
Suction Pressure (psi)	19.285
Discharge Pressure (psi)	203
Inlet Temperature (°F)	-0.4
Outlet Temperature (°F)	154.832
Material of Construction	Stainless Steel
Driver (hp)	800
Nitrogen Compressor	
Power (kW)	147.3
Suction Pressure (psi)	70
Discharge Pressure (psi)	580
Inlet Temperature (°F)	77
Outlet Temperature (°F)	596.7
Material of Construction	Stainless Steel
Driver (hp)	60
Hydrogen Compressor	
Power (kW)	37.35
Suction Pressure (psi)	464
Discharge Pressure (psi)	568
Inlet Temperature (°F)	77
Outlet Temperature (°F)	119.5
Material of Construction	Stainless Steel
Driver (hp)	15

Catalyst		
Calculations		
Catalyt Price	$ 720.00	ft3
Volume	148.24	
$	$ 106,734	
*catalyst price from company quote		

Cooling Water		
Flow	54.18	m3/hr
Flow	474616.8	m3/yr
Flow	474.6168	1000m3/yr

Price	14.8	$/1000m3
Price	$ 6,743	$/yr
*book price		
Propane		
Flow	11190	kg/h
Propane	$ 6.00	$/kg
Total Cost (Cap)	$ 67,140	

Appendix D: Electrolysis Calculations

Water needed per day [mol/day]	4.37E+06
gal/day of water	2.09E+04
$ Water per 1000 m3	1.48E-02
$Water per US gallon	5.60E-05
$Water per day	1.17E+00
$Water per year	4.26E+02

O2 Produced [mol/day]	2.18E+06
O2 Produced [kg/day]	3.49E+04

Std Heat of Formation for H20 [kJ/mol]	-286
Water needed per day [mol/day]	4.37E+06
Energy needed [kJ/h]	5.20E+07
kWh for one day	3.47E+05

Appendix E: Adsorption Calculations

		Absorber 1	Absorber 2
Mass Balance Calculator	Volume %	Flow Rate (SCFH)	Flow Rate (SCFH)
Stream 1: Inlet Air		16456	16456
Nitrogen	0.79	13000	13000
Oxygen	0.21	3456	3456
Stream 2: Purified Nitrogen		13000	13000
Stream 3: Oxygen Waste		3456	3456

Pricing			
Equipment	**Unit Price**	**Quanitity**	**Total Cost**
Adsorber	$ 400,000.00	2	$800,000
N2 Receiver	$ 14,680.00	2	$29,360
AMP	$ 2,680.00	2	$5,360
Total			**$834,720**

Compressor - Centrifugal			
Specifications		**Pricing and Factors**	
Power (kW)	3000	Base Case Purchase Cost (Cpo)	
Discharge Pressure (barg)	6.89	$	323.21
Material	Carbon Steel	Bare Module Factor (Fbm)	
Constants		2.7	
K1	2.2897	Pressure Factor (Fp)	
K2	1.3604	1	
K3	-0.1027	Purchase Price Mid Year 2019 (Cp)	
C1	0	$	1,327.67
C2	0		
C3	0		

Carbon Filter - Cartridge			
Specifications		**Pricing and Factors**	
Area (m^2)	4000	Base Case Purchase Cost (Cpo)	
Material	Cartidge	393.24	
Constants		Bare Module Factor (Fbm)	
K1	3.2107	1.65	
K2	0.7597	Bare Module Cost in 2001 (Cbm)	
K3	0.0021	$	648.85
		Bare Module Cost Mid 2019	
		$	987.17

*

Air Buffer Tank			
Specifications		**Pricing and Factors**	
Type	Vertical	Column Volume (A) (m^3)	
Diameter (m)	1	0.8	
Length (m)	1	Base Case Purchase Cost (Cpo)	
Pressure (barg)	110	$	2,828
Material	Carbon Steel	Pressure Factor (Fp)	
Constants		11.75	
K1	3.4974	Module Factor (Fm)	
K2	0.4485	1	
K3	0.1074	Purchase Price in 2001 (Cp)	
tmin	0.0063	$	33,219
S	944	Purchase Price Mid 2019	
E	0.9	$	50,540.36
CA	0.00315	Bare Module Factor in 2001 (Cbm)	
B1	2.25	$	66,823
B2	1.82	Bare Module Factor Mid 2019	
		$	101,665.32

Nitrogen Storage Tank		
Specifications		**Pricing and Factors**
Type	Vertical	Column Volume (A) (m^3)
Diameter (m)	1.0668	2.8
Length (m)	3.175	Base Case Purchase Cost (Cpo)
Pressure (barg)	80	$ 5,280
Material	Carbon Steel	Pressure Factor (Fp)
Constants		9.06
K1	3.4974	Module Factor (Fm)
K2	0.4485	1
K3	0.1074	Purchase Price in 2001 (Cp)
tmin	0.0063	$ 47,821
S	944	Purchase Price Mid 2019
E	0.9	$ 72,755.48
CA	0.00315	Bare Module Factor in 2001 (Cbm)
B1	2.25	$ 98,914
B2	1.82	Bare Module Factor Mid 2019
		$ 150,488.32

Appendix F: ASPEN Hysys Report

****

INPUT SUMMARY

****

FLUID PACKAGE: Basis-1(Peng-Robinson)

Property Package Type: PengRob
Component List - 1: Hydrogen /Nitrogen /Ammonia /Air /Propane /H2O /Oxygen /

Reaction Set: Set-1

Reaction 'Rxn-1':
Reactants: Hydrogen, Stoich Coeff -3 / Nitrogen, Stoich Coeff -1 / Ammonia, Stoich Coeff 2 /

Basis Data: Basis = Partial Pres / Component = Nitrogen / Phase = Overall / RateUnits = kgmole/m3-s /

Kinetic Coefficients: Fwd Freq Factor = 17895.4 / Fwd Activation Energy = 87027.1039 /

FLOWSHEET: Main

Fluid Package: Basis-1

STREAM: 1 Hydrogen (Material Stream)
Temperature = 74.3333333 C
Pressure = 4017.54816 kPa
Molar Flow = 36.75 kgmole/h
Composition Basis (In Mole Flows):Hydrogen = 36.75/ Nitrogen = 0/ Ammonia = 0/ Air = 0/ Propane = 0/ H2O = 0/ Oxygen = 0/

STREAM: 2 Nitrogen (Material Stream)
Temperature = 313.722222 C
Pressure = 4101.325 kPa
Molar Flow = 12.25 kgmole/h
Composition Basis (In Mass Flows):Hydrogen = 0/ Nitrogen = 343.159256/ Ammonia = 0/ Air = 0/ Propane = 0/ H2O = 0/ Oxygen = 0/

UNIT OPERATION: MIX-100 (Mixer)
Feed Stream = 1 Hydrogen
Feed Stream = 2 Nitrogen
Feed Stream = 8-recycle
Product Stream = 3
UseTrivialSolution = True
Pressure Specification=Set to lowest inlet

STREAM: 3 (Material Stream)

UNIT OPERATION: PFR-100 (Plug Flow Reactor)
Feed Stream = 4a
Product Stream = 5
Reaction Set=Set-1
Delta P = 14 kPa
NumberOfSegments = 40
TubeTotalVolume = 2.671 m3
TubeDiameter = 0.768 m

STREAM: 5 (Material Stream)

UNIT OPERATION: K-100 (Compressor)
Feed Stream = 3
Product Stream = 4
Energy Stream = K100
CurveCollectionName = CC-0
SelectedCurveCollection = True
NumberOfCurves = 0
NumberOfCurves = 0
NumberOfCurves = 0

EffCurveType = 0
NumberOfCurves = 0

STREAM: 4 (Material Stream)
Pressure = 12101.325 kPa

STREAM: K100 (Energy Stream)

STREAM: 6 (Material Stream)
Temperature = -10 C

UNIT OPERATION: V-100 (Separator)
Feed Stream = 6
Vapour Product = 7
Liquid Product = 9
Delta P = 8000 kPa

STREAM: 7 (Material Stream)

STREAM: 9 (Material Stream)

UNIT OPERATION: RCY-1 (Recycle)
Inlet Stream = 7
Output Stream = 8-recycle

STREAM: 8-recycle (Material Stream)
Temperature = -20.5297459 C
Pressure = 4017.325 kPa
Molar Flow = 115.426999 kgmole/h
Composition Basis (In Mass Flows):Hydrogen = 150.421581/ Nitrogen = 960.696254/ Ammonia = 111.009445/ Air = 0/ Propane = 0/ H2O = 0/ Oxygen = 0/

UNIT OPERATION: Condenser (Heat Exchanger)
TubeInletStream = 5a
TubeOutletStream = 6
ShellInletStream = 10
ShellOutletStream = 11
TubeOuterDiameter = 20 mm
TubeInnerDiameter = 16 mm
TubeThickness = FEMPTY mm
HCurveName = 5a-6
HCurveName = 10-11
ShellPressureDrop = 9.80665205 kPa
TubePressureDrop = 40 kPa

UNIT OPERATION: VLV-101-2 (Valve)
Feed Stream = 13
Product Stream = 10
ValveManufacturer = FISHER

ValveManufacturerType = 0
C1 = 33.4664011
RigorousSizingMethod = True
UseXtTable = False
RigorousFlowCalc = True

UNIT OPERATION: K-101 (Compressor)
Feed Stream = 11
Product Stream = 12
Energy Stream = Q Compressor-2
CurveCollectionName = CC-0
SelectedCurveCollection = True
NumberOfCurves = 0
NumberOfCurves = 0
NumberOfCurves = 0
EffCurveType = 0
NumberOfCurves = 0

STREAM: 10 (Material Stream)
Temperature = -20 C

STREAM: 11 (Material Stream)
Temperature = -18 C
Composition Basis (In Mole Fractions):Hydrogen = 0/ Nitrogen = 0/ Ammonia = 0/ Air = 0/ Propane = 1/ H2O = 0/ Oxygen = 0/

STREAM: 12 (Material Stream)
Pressure = 1501.325 kPa

STREAM: Q Compressor-2 (Energy Stream)

UNIT OPERATION: Cooler (Heat Exchanger)
TubeInletStream = 14-cw inlet
TubeOutletStream = 15 - cw outlet
ShellInletStream = 12
ShellOutletStream = 13
TubeOuterDiameter = 20 mm
TubeInnerDiameter = 16 mm
TubeThickness = FEMPTY mm
HCurveName = 14-cw inlet-15 - cw outlet
HCurveName = 12-13
ShellPressureDrop = 9.80665205 kPa
TubePressureDrop = 98.0665205 kPa

STREAM: 14-cw inlet (Material Stream)
Temperature = 25 C
Pressure = 202.325 kPa
Composition Basis (In Mass Flows):Hydrogen = 0/ Nitrogen = 0/ Ammonia = 0/ Air = 0/ Propane = 0/ H2O = 53439.447/ Oxygen = 0/

STREAM: 15 - cw outlet (Material Stream)
  Temperature = 42 C

STREAM: 13 (Material Stream)
  Vapour Fraction = 0

UNIT OPERATION: E-100 (Heat Exchanger)
  TubeInletStream = 4
  TubeOutletStream = 4a
  ShellInletStream = 5
  ShellOutletStream = 5a
  TubeOuterDiameter = 20 mm
  TubeInnerDiameter = 16 mm
  TubeThickness = FEMPTY mm
  HCurveName = 4-4a
  HCurveName = 5-5a
  ShellPressureDrop = 15 kPa
  TubePressureDrop = 15 kPa

STREAM: 4a (Material Stream)
  Temperature = 415 C

STREAM: 5a (Material Stream)

UNIT OPERATION: K-102 (Compressor)
  Feed Stream = 1
  Product Stream = leaving nitrogen
  Energy Stream = K19
  CurveCollectionName = CC-0
  SelectedCurveCollection = True
  NumberOfCurves = 0
  NumberOfCurves = 0
  NumberOfCurves = 0
  EffCurveType = 0
  NumberOfCurves = 0

STREAM: 1 (Material Stream)
  Temperature = 25 C
  Pressure = 581.325 kPa
  Molar Flow = 61.2582781 kgmole/h
  Composition Basis (In Mass Flows):Hydrogen = 0/ Nitrogen = 1716.02818/ Ammonia = 0/ Air = 0/ Propane = 0/ H2O = 0/ Oxygen = 0/

STREAM: K19 (Energy Stream)

UNIT OPERATION: K-102-2 (Compressor)
  Feed Stream = 1-2

Product Stream = hydrogen leaving
Energy Stream = K19-2
CurveCollectionName = CC-0
SelectedCurveCollection = True
NumberOfCurves = 0
NumberOfCurves = 0
NumberOfCurves = 0
EffCurveType = 0
NumberOfCurves = 0

STREAM: 1-2 (Material Stream)
Temperature = 48.8888889 C
Pressure = 3300.49322 kPa
Molar Flow = 183.752155 kgmole/h
Composition Basis (In Mass Flows):Hydrogen = 370.44435/ Nitrogen = 0/ Ammonia = 0/ Air = 0/ Propane = 0/ H2O = 0/ Oxygen = 0/

STREAM: K19-2 (Energy Stream)

STREAM: 2 (Material Stream)
Temperature = 48.6111111 C
Pressure = 3410.80936 kPa
Mass Flow = 1455.35417 kg/h
Composition Basis (In Mole Fractions):Hydrogen = 0/ Nitrogen = 0/ Ammonia = 0/ Air = 0/ Propane = 0/ H2O = 0/ Oxygen = 1/

STREAM: hydrogen leaving (Material Stream)
Pressure = 4017.54816 kPa

STREAM: leaving nitrogen (Material Stream)
Pressure = 4100.28527 kPa

##

OUTPUT SUMMARY

##

OKLAHOMA STATE UNIVERSIT Case Name: Ammonia Absorption Simple GM high temperature.hsc

Bedford, MA
USA Unit Set: SI

Date/Time: Thu Apr 02 04:23:10 2020

Basis-1 (Fluid Package): Component List

Fluid Package: Basis-1

COMPONENT LIST

Component List - 1 [HYSYS Databanks]

COMPONENT	TYPE	MOLECULAR WEIGHT	BOILING PT (C)	IDEAL LIQ DENSITY (kg/m3)	CRITICAL TEMP (C)
Hydrogen	Pure	2.016	-252.6	69.86	-239.7
Nitrogen	Pure	28.01	-195.8	806.4	-147.0
Ammonia	Pure	17.03	-33.45	616.1	132.4
Air	Pure	28.95	-194.5	879.6	-140.7
Propane	Pure	44.10	-42.10	506.7	96.75
H2O	Pure	18.02	100.0	998.0	374.1
Oxygen	Pure	32.00	-183.0	1138	-118.4

(Continued..) Component List - 1 [HYSYS Databanks]

COMPONENT	CRITICAL PRES (kPa)	CRITICAL VOL (m3/kgmole)	ACENTRICITY	HEAT OF FORM (kJ/kgmole)
Hydrogen	1316	5.150e-002	-0.1201	0.0000
Nitrogen	3394	9.000e-002	4.000e-002	0.0000
Ammonia	1.128e+004	8.040e-002	0.2550	-4.571e+004
Air	3774	9.147e-002	3.446e-002	0.0000
Propane	4257	0.2000	0.1524	-1.039e+005
H2O	2.212e+004	5.710e-002	0.3440	-2.418e+005
Oxygen	5080	7.320e-002	1.900e-002	0.0000

Case (Simulation Case): Mass and Energy Balance, Utility Balance, Process CO2 Emissions

---

Simulation Case: Case

OVERALL MASS BALANCE

In Stream	Count	Mass Flow (kg/h)	Out Stream	Count	Mass Flow (kg/h)
1 Hydrogen	Yes	74.09	9	Yes	417.3
2 Nitrogen	Yes	343.2	15 - cw outlet	Yes	5.344e+004
14-cw inlet	Yes	5.344e+004	leaving nitrogen	Yes	1716

1	Yes	1716	hydrogen leaving	Yes	370.4
1-2	Yes	370.4			

Total In MassFlow (kg/h) 5.594e+004 Total Out MassFlow (kg/h) 5.594e+004
Mass Imbalance (kg/h) 4.015e-002 Rel Mass Imbalance Pct (%) 0.00

OVERALL ENERGY BALANCE

InStream	Count	Energy Flow (kJ/h)	OutStream	Count	Energy Flow (kJ/h)
1 Hydrogen	Yes	5.201e+04	9	Yes	-1.725e+06
2 Nitrogen	Yes	1.055e+05	15 - cw outlet	Yes	-8.451e+08
K100	Yes	7.209e+05	leaving nitrogen	Yes	5.277e+05
Q Compressor-2	Yes	1.312e+06	hydrogen leaving	Yes	2.600e+05
14-cw inlet	Yes	-8.490e+08			
1	Yes	-2.711e+03			
K19	Yes	5.304e+05			
1-2	Yes	1.255e+05			
K19-2	Yes	1.344e+05			

Total In EnergyFlow (kJ/h) -8.461e+008 Total Out EnergyFlow (kJ/h) -8.461e+008
Energy Imbalance (kJ/h) -850.5 Rel Energy Imbalance Pct (%) 0.00

OVERALL UTILITY BALANCE

Utility Name	Usage Info	Energy Flow	Mass Flow	Cost

Hot Utility Summary	Cold Utility Summary
Utility Flow ---	Utility Flow ---
Utility Cost ---	Utility Cost ---
Carbon Emiss. ---	Carbon Emiss. ---
Carbon Fees ---	Carbon Fees ---

PROCESS CO2 EMISSIONS

Inlet Stream	Count	IFPP (1995) (kg/h)	IFPP (2007) (kg/h)	EPA (2009) (kg/h)
1 Hydrogen	Yes	0.000e-01	0.000e-01	0.000e-01
2 Nitrogen	Yes	0.000e-01	0.000e-01	0.000e-01
14-cw inlet	Yes	0.000e-01	0.000e-01	0.000e-01
1	Yes	0.000e-01	0.000e-01	0.000e-01
1-2	Yes	0.000e-01	0.000e-01	0.000e-01
Total from Inlets		---	---	---
Total Carbon Fees from Inlets (Cost/hr)		---	---	---

Outlet Stream	Count	IFPP (1995) (kg/h)	IFPP (2007) (kg/h)	EPA (2009) (kg/h)
9	Yes	0.000e-01	0.000e-01	0.000e-01
15 - cw outlet	Yes	0.000e-01	0.000e-01	0.000e-01
leaving nitrogen	Yes	0.000e-01	0.000e-01	0.000e-01
hydrogen leaving	Yes	0.000e-01	0.000e-01	0.000e-01
Total from Outlets		---	---	---
Total Carbon Fees		---	---	---

from Outlets (Cost/hr)

----

1 Hydrogen (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 1 Hydrogen Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	74.33	74.33
Pressure: (kPa)	4018	4018
Molar Flow (kgmole/h)	36.75	36.75
Mass Flow (kg/h)	74.09	74.09
Std Ideal Liq VolFlow (m3/h)	1.061	1.061
Molar Enthalpy (kJ/kgmole)	1.415e+03	1.415e+03
Molar Entropy (kJ/kgmole-C)	9.669e+01	9.669e+01
Heat Flow (kJ/h)	5.201e+04	5.201e+04
Liq VolFlow @Std Cond (m3/h)	869.2	869.2

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	36.75	1.0000	74.09	1.0000	1.061	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	36.75	1.0000	74.09	1.0000	1.061	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	36.75	1.0000	74.09	1.0000	1.061	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Total	36.75	1.0000	74.09	1.0000	1.061	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Mixer: MIX-100		

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

2 Nitrogen (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 2 Nitrogen Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	313.7	313.7
Pressure: (kPa)	4101	4101
Molar Flow (kgmole/h)	12.25	12.25
Mass Flow (kg/h)	343.2	343.2
Std Ideal Liq VolFlow (m3/h)	0.4256	0.4256
Molar Enthalpy (kJ/kgmole)	8.615e+03	8.615e+03
Molar Entropy (kJ/kgmole-C)	1.374e+02	1.374e+02
Heat Flow (kJ/h)	1.055e+05	1.055e+05
Liq VolFlow @Std Cond (m3/h)	289.5	289.5

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC

(kgmole/h) (kg/h) (m3/h)

Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	12.25	1.0000	343.2	1.0000	0.4256	1.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	12.25	1.0000	343.2	1.0000	0.4256	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	12.25	1.0000	343.2	1.0000	0.4256	1.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	12.25	1.0000	343.2	1.0000	0.4256	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Mixer: MIX-100		

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

3 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 3 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	25.40	25.40
Pressure: (kPa)	4017	4017
Molar Flow (kgmole/h)	164.4	164.4
Mass Flow (kg/h)	1639	1639
Std Ideal Liq VolFlow (m3/h)	5.011	5.011
Molar Enthalpy (kJ/kgmole)	-1.887e+03	-1.887e+03
Molar Entropy (kJ/kgmole-C)	1.073e+02	1.073e+02
Heat Flow (kJ/h)	-3.103e+05	-3.103e+05
Liq VolFlow @Std Cond (m3/h)	3888	3888

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	111.4	0.6773	224.5	0.1369	3.214	0.6414
Nitrogen	46.54	0.2831	1304	0.7953	1.617	0.3227
Ammonia	6.518	0.0396	111.0	0.0677	0.1802	0.0360
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	164.4	1.0000	1639	1.0000	5.011	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	111.4	0.6773	224.5	0.1369	3.214	0.6414
Nitrogen	46.54	0.2831	1304	0.7953	1.617	0.3227
Ammonia	6.518	0.0396	111.0	0.0677	0.1802	0.0360
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	164.4	1.0000	1639	1.0000	5.011	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---

H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Compressor: K-100	Mixer: MIX-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

5 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 5 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	1.0000	1.0000	0.0000
Temperature: (C)	676.7	676.7	676.7
Pressure: (kPa)	1.207e+004	1.207e+004	1.207e+004
Molar Flow (kgmole/h)	140.0	140.0	0.0000
Mass Flow (kg/h)	1639	1639	0.0000
Std Ideal Liq VolFlow (m3/h)	4.203	4.203	0.0000
Molar Enthalpy (kJ/kgmole)	1.163e+04	1.163e+04	1.159e+04
Molar Entropy (kJ/kgmole-C)	1.461e+02	1.461e+02	1.461e+02
Heat Flow (kJ/h)	1.628e+06	1.628e+06	0.000e-01
Liq VolFlow @Std Cond (m3/h)	3307	3307	0.0000

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.67	0.5335	150.5	0.0918	2.155	0.5126
Nitrogen	34.31	0.2452	961.2	0.5863	1.192	0.2836
Ammonia	30.98	0.2214	527.7	0.3219	0.8565	0.2038
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	140.0	1.0000	1639	1.0000	4.203	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.67	0.5335	150.5	0.0918	2.155	0.5126
Nitrogen	34.31	0.2452	961.2	0.5863	1.192	0.2836
Ammonia	30.98	0.2214	527.7	0.3219	0.8565	0.2038
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	140.0	1.0000	1639	1.0000	4.203	1.0000

Liquid Phase Phase Fraction 0.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.5328	0.0000	0.0916	0.0000	0.5120
Nitrogen	0.0000	0.2449	0.0000	0.5853	0.0000	0.2833
Ammonia	0.0000	0.2223	0.0000	0.3230	0.0000	0.2046
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	1.001	1.001	---
Nitrogen	1.001	1.001	---
Ammonia	0.9958	0.9958	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Heat Exchanger: E-100	Plug Flow Reactor: PFR-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

Material Stream: 4 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	173.2	173.2
Pressure: (kPa)	1.210e+004	1.210e+004
Molar Flow (kgmole/h)	164.4	164.4
Mass Flow (kg/h)	1639	1639
Std Ideal Liq VolFlow (m3/h)	5.011	5.011
Molar Enthalpy (kJ/kgmole)	2.498e+03	2.498e+03
Molar Entropy (kJ/kgmole-C)	1.099e+02	1.099e+02
Heat Flow (kJ/h)	4.107e+05	4.107e+05
Liq VolFlow @Std Cond (m3/h)	3888	3888

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	111.4	0.6773	224.5	0.1369	3.214	0.6414
Nitrogen	46.54	0.2831	1304	0.7953	1.617	0.3227
Ammonia	6.518	0.0396	111.0	0.0677	0.1802	0.0360
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	164.4	1.0000	1639	1.0000	5.011	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	111.4	0.6773	224.5	0.1369	3.214	0.6414
Nitrogen	46.54	0.2831	1304	0.7953	1.617	0.3227
Ammonia	6.518	0.0396	111.0	0.0677	0.1802	0.0360
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	164.4	1.0000	1639	1.0000	5.011	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---

Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Heat Exchanger: E-100	Compressor: K-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

---

6 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

---

Material Stream: 6 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	0.8103	0.8103	0.1897
Temperature: (C)	-10.00	-10.00	-10.00
Pressure: (kPa)	1.202e+004	1.202e+004	1.202e+004
Molar Flow (kgmole/h)	140.0	113.4	26.55
Mass Flow (kg/h)	1639	1189	450.2
Std Ideal Liq VolFlow (m3/h)	4.203	3.469	0.7344
Molar Enthalpy (kJ/kgmole)	-1.567e+04	-3.195e+03	-6.895e+04
Molar Entropy (kJ/kgmole-C)	8.996e+01	9.438e+01	7.108e+01
Heat Flow (kJ/h)	-2.193e+06	-3.623e+05	-1.830e+06
Liq VolFlow @Std Cond (m3/h)	3307	2682	0.7437

COMPOSITION

Overall Phase Vapour Fraction 0.8103

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.67	0.5335	150.5	0.0918	2.155	0.5126
Nitrogen	34.31	0.2452	961.2	0.5863	1.192	0.2836
Ammonia	30.98	0.2214	527.7	0.3219	0.8565	0.2038
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	140.0	1.0000	1639	1.0000	4.203	1.0000

Vapour Phase Phase Fraction 0.8103

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.51	0.6569	150.2	0.1263	2.150	0.6198
Nitrogen	34.26	0.3021	959.9	0.8072	1.190	0.3432
Ammonia	4.644	0.0409	79.09	0.0665	0.1284	0.0370
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	113.4	1.0000	1189	1.0000	3.469	1.0000

Liquid Phase Phase Fraction 0.1897

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.1600	0.0060	0.3225	0.0007	4.616e-003	0.0063
Nitrogen	4.723e-002	0.0018	1.323	0.0029	1.641e-003	0.0022
Ammonia	26.34	0.9922	448.6	0.9963	0.7281	0.9915
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	26.55	1.0000	450.2	1.0000	0.7344	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	109.0	109.0	---
Nitrogen	169.8	169.8	---
Ammonia	4.127e-002	4.127e-002	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Separator: V-100	Heat Exchanger: Condenser	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

7 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 7 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	1.0000	1.0000	0.0000
Temperature: (C)	-20.57	-20.57	-20.57
Pressure: (kPa)	4017	4017	4017
Molar Flow (kgmole/h)	115.4	115.4	0.0000
Mass Flow (kg/h)	1222	1222	0.0000
Std Ideal Liq VolFlow (m3/h)	3.525	3.525	0.0000
Molar Enthalpy (kJ/kgmole)	-4.049e+03	-4.049e+03	-7.033e+04
Molar Entropy (kJ/kgmole-C)	1.039e+02	1.039e+02	6.797e+01
Heat Flow (kJ/h)	-4.674e+05	-4.674e+05	0.000e-01
Liq VolFlow @Std Cond (m3/h)	2729	2729	0.0000

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.62	0.6465	150.4	0.1231	2.154	0.6109
Nitrogen	34.30	0.2971	960.8	0.7862	1.192	0.3380
Ammonia	6.507	0.0564	110.8	0.0907	0.1799	0.0510
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	115.4	1.0000	1222	1.0000	3.525	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.62	0.6465	150.4	0.1231	2.154	0.6109
Nitrogen	34.30	0.2971	960.8	0.7862	1.192	0.3380
Ammonia	6.507	0.0564	110.8	0.0907	0.1799	0.0510
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	115.4	1.0000	1222	1.0000	3.525	1.0000

Liquid Phase Phase Fraction 0.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0017	0.0000	0.0002	0.0000	0.0018
Nitrogen	0.0000	0.0005	0.0000	0.0009	0.0000	0.0007
Ammonia	0.0000	0.9978	0.0000	0.9989	0.0000	0.9976
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	384.5	384.5	---
Nitrogen	565.3	565.3	---
Ammonia	5.649e-002	5.649e-002	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Recycle: RCY-1	Separator: V-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

9 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 9 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	0.0000	0.0000	1.0000
Temperature: (C)	-20.57	-20.57	-20.57
Pressure: (kPa)	4017	4017	4017
Molar Flow (kgmole/h)	24.53	0.0000	24.53
Mass Flow (kg/h)	417.3	0.0000	417.3

Std Ideal Liq VolFlow (m3/h)	0.6783	0.0000	0.6783
Molar Enthalpy (kJ/kgmole)	-7.033e+04	-4.049e+03	-7.033e+04
Molar Entropy (kJ/kgmole-C)	6.797e+01	1.039e+02	6.797e+01
Heat Flow (kJ/h)	-1.725e+06	0.000e-01	-1.725e+06
Liq VolFlow @Std Cond (m3/h)	0.6837	0.0000	0.6837

COMPOSITION

Overall Phase Vapour Fraction 0.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	4.125e-002	0.0017	8.316e-002	0.0002	1.190e-003	0.0018
Nitrogen	1.289e-002	0.0005	0.3612	0.0009	4.479e-004	0.0007
Ammonia	24.48	0.9978	416.8	0.9989	0.6766	0.9976
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	24.53	1.0000	417.3	1.0000	0.6783	1.0000

Vapour Phase Phase Fraction 0.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.6465	0.0000	0.1231	0.0000	0.6109
Nitrogen	0.0000	0.2971	0.0000	0.7862	0.0000	0.3380
Ammonia	0.0000	0.0564	0.0000	0.0907	0.0000	0.0510
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Liquid Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	4.125e-002	0.0017	8.316e-002	0.0002	1.190e-003	0.0018
Nitrogen	1.289e-002	0.0005	0.3612	0.0009	4.479e-004	0.0007
Ammonia	24.48	0.9978	416.8	0.9989	0.6766	0.9976
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	24.53	1.0000	417.3	1.0000	0.6783	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY

Hydrogen	384.5	384.5	---
Nitrogen	565.3	565.3	---
Ammonia	5.649e-002	5.649e-002	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
	Separator: V-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

8-recycle (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 8-recycle Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	-20.53	-20.53
Pressure: (kPa)	4017	4017
Molar Flow (kgmole/h)	115.4	115.4
Mass Flow (kg/h)	1222	1222
Std Ideal Liq VolFlow (m3/h)	3.525	3.525
Molar Enthalpy (kJ/kgmole)	-4.053e+03	-4.053e+03
Molar Entropy (kJ/kgmole-C)	1.039e+02	1.039e+02
Heat Flow (kJ/h)	-4.678e+05	-4.678e+05
Liq VolFlow @Std Cond (m3/h)	2729	2729

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.61	0.6464	150.4	0.1231	2.153	0.6109
Nitrogen	34.29	0.2971	960.7	0.7861	1.191	0.3380
Ammonia	6.518	0.0565	111.0	0.0908	0.1802	0.0511
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	115.4	1.0000	1222	1.0000	3.525	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.61	0.6464	150.4	0.1231	2.153	0.6109
Nitrogen	34.29	0.2971	960.7	0.7861	1.191	0.3380
Ammonia	6.518	0.0565	111.0	0.0908	0.1802	0.0511
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	115.4	1.0000	1222	1.0000	3.525	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Mixer: MIX-100	Recycle: RCY-1	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

10 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 10 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	0.4259	0.4259	0.5741

Temperature: (C)	-20.00	-20.00	-20.00
Pressure: (kPa)	244.2	244.2	244.2
Molar Flow (kgmole/h)	252.2	107.4	144.8
Mass Flow (kg/h)	1.112e+004	4736	6383
Std Ideal Liq VolFlow (m3/h)	21.95	9.347	12.60
Molar Enthalpy (kJ/kgmole)	-1.176e+05	-1.074e+05	-1.251e+05
Molar Entropy (kJ/kgmole-C)	1.020e+02	1.422e+02	7.219e+01
Heat Flow (kJ/h)	-2.965e+07	-1.154e+07	-1.812e+07
Liq VolFlow @Std Cond (m3/h)	21.90	9.329	12.57

COMPOSITION

Overall Phase Vapour Fraction 0.4259

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

Vapour Phase Phase Fraction 0.4259

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	107.4	1.0000	4736	1.0000	9.347	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	107.4	1.0000	4736	1.0000	9.347	1.0000

Liquid Phase Phase Fraction 0.5741

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	144.8	1.0000	6383	1.0000	12.60	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Total	144.8	1.0000	6383	1.0000	12.60	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	1.000	1.000	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Heat Exchanger: Condenser	Valve: VLV-101-2	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

11 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 11 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	-18.00	-18.00
Pressure: (kPa)	234.4	234.4
Molar Flow (kgmole/h)	252.2	252.2
Mass Flow (kg/h)	1.112e+004	1.112e+004
Std Ideal Liq VolFlow (m3/h)	21.95	21.95
Molar Enthalpy (kJ/kgmole)	-1.073e+05	-1.073e+05
Molar Entropy (kJ/kgmole-C)	1.431e+02	1.431e+02
Heat Flow (kJ/h)	-2.705e+07	-2.705e+07
Liq VolFlow @Std Cond (m3/h)	21.90	21.90

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC

(kgmole/h) (kg/h) (m3/h)

Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Compressor: K-101	Heat Exchanger: Condenser	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

12 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 12 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	68.24	68.24
Pressure: (kPa)	1501	1501
Molar Flow (kgmole/h)	252.2	252.2
Mass Flow (kg/h)	1.112e+004	1.112e+004
Std Ideal Liq VolFlow (m3/h)	21.95	21.95
Molar Enthalpy (kJ/kgmole)	-1.021e+05	-1.021e+05
Molar Entropy (kJ/kgmole-C)	1.470e+02	1.470e+02
Heat Flow (kJ/h)	-2.574e+07	-2.574e+07
Liq VolFlow @Std Cond (m3/h)	21.90	21.90

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---

H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Heat Exchanger: Cooler	Compressor: K-101	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

14-cw inlet (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 14-cw inlet Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	AQUEOUS PH.
Vapour / Phase Fraction	0.0000	1.0000
Temperature: (C)	25.00	25.00
Pressure: (kPa)	202.3	202.3
Molar Flow (kgmole/h)	2966	2966
Mass Flow (kg/h)	5.344e+004	5.344e+004
Std Ideal Liq VolFlow (m3/h)	53.55	53.55
Molar Enthalpy (kJ/kgmole)	-2.862e+05	-2.862e+05
Molar Entropy (kJ/kgmole-C)	5.370e+01	5.370e+01
Heat Flow (kJ/h)	-8.490e+08	-8.490e+08
Liq VolFlow @Std Cond (m3/h)	52.66	52.66

COMPOSITION

Overall Phase Vapour Fraction 0.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	2966	1.0000	5.344e+004	1.0000	53.55	1.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	2966	1.0000	5.344e+004	1.0000	53.55	1.0000

Aqueous Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	2966	1.0000	5.344e+004	1.0000	53.55	1.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	2966	1.0000	5.344e+004	1.0000	53.55	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	0.0000	---	0.0000
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Heat Exchanger: Cooler		

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

15 - cw outlet (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 15 - cw outlet Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	AQUEOUS PH.
Vapour / Phase Fraction	0.0000	1.0000
Temperature: (C)	42.00	42.00
Pressure: (kPa)	104.3	104.3
Molar Flow (kgmole/h)	2966	2966
Mass Flow (kg/h)	5.344e+004	5.344e+004
Std Ideal Liq VolFlow (m3/h)	53.55	53.55

Molar Enthalpy (kJ/kgmole)	-2.849e+05	-2.849e+05
Molar Entropy (kJ/kgmole-C)	5.801e+01	5.801e+01
Heat Flow (kJ/h)	-8.451e+08	-8.451e+08
Liq VolFlow @Std Cond (m3/h)	52.66	52.66

COMPOSITION

Overall Phase Vapour Fraction 0.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	2966	1.0000	5.344e+004	1.0000	53.55	1.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	2966	1.0000	5.344e+004	1.0000	53.55	1.0000

Aqueous Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	2966	1.0000	5.344e+004	1.0000	53.55	1.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	2966	1.0000	5.344e+004	1.0000	53.55	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	0.0000	---	0.0000
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
	Heat Exchanger: Cooler	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----
13 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments
----
Material Stream: 13 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	LIQUID PH.	VAPOUR PH.
Vapour / Phase Fraction	0.0000	1.0000	0.0000
Temperature: (C)	43.60	43.60	43.60
Pressure: (kPa)	1492	1492	1492
Molar Flow (kgmole/h)	252.2	252.2	0.0000
Mass Flow (kg/h)	1.112e+004	1.112e+004	0.0000
Std Ideal Liq VolFlow (m3/h)	21.95	21.95	0.0000
Molar Enthalpy (kJ/kgmole)	-1.176e+05	-1.176e+05	-1.044e+05
Molar Entropy (kJ/kgmole-C)	9.828e+01	9.828e+01	1.401e+02
Heat Flow (kJ/h)	-2.965e+07	-2.965e+07	0.000e-01
Liq VolFlow @Std Cond (m3/h)	21.90	21.90	0.0000

COMPOSITION

Overall Phase Vapour Fraction 0.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

Liquid Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	252.2	1.0000	1.112e+004	1.0000	21.95	1.0000

Vapour Phase Phase Fraction 0.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	1.000	1.000	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Valve: VLV-101-2	Heat Exchanger: Cooler	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

4a (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 4a Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	415.0	415.0

Pressure: (kPa)	1.209e+004	1.209e+004
Molar Flow (kgmole/h)	164.4	164.4
Mass Flow (kg/h)	1639	1639
Std Ideal Liq VolFlow (m3/h)	5.011	5.011
Molar Enthalpy (kJ/kgmole)	9.901e+03	9.901e+03
Molar Entropy (kJ/kgmole-C)	1.232e+02	1.232e+02
Heat Flow (kJ/h)	1.628e+06	1.628e+06
Liq VolFlow @Std Cond (m3/h)	3888	3888

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	111.4	0.6773	224.5	0.1369	3.214	0.6414
Nitrogen	46.54	0.2831	1304	0.7953	1.617	0.3227
Ammonia	6.518	0.0396	111.0	0.0677	0.1802	0.0360
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	164.4	1.0000	1639	1.0000	5.011	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	111.4	0.6773	224.5	0.1369	3.214	0.6414
Nitrogen	46.54	0.2831	1304	0.7953	1.617	0.3227
Ammonia	6.518	0.0396	111.0	0.0677	0.1802	0.0360
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	164.4	1.0000	1639	1.0000	5.011	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION

Plug Flow Reactor: PFR-100 Heat Exchanger: E-100
UTILITIES

(No utilities reference this stream)
PROCESS UTILITY

5a (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments
----
Material Stream: 5a   Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	432.6	432.6
Pressure: (kPa)	1.206e+004	1.206e+004
Molar Flow (kgmole/h)	140.0	140.0
Mass Flow (kg/h)	1639	1639
Std Ideal Liq VolFlow (m3/h)	4.203	4.203
Molar Enthalpy (kJ/kgmole)	2.931e+03	2.931e+03
Molar Entropy (kJ/kgmole-C)	1.355e+02	1.355e+02
Heat Flow (kJ/h)	4.102e+05	4.102e+05
Liq VolFlow @Std Cond (m3/h)	3307	3307

COMPOSITION

Overall Phase   Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.67	0.5335	150.5	0.0918	2.155	0.5126
Nitrogen	34.31	0.2452	961.2	0.5863	1.192	0.2836
Ammonia	30.98	0.2214	527.7	0.3219	0.8565	0.2038
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	140.0	1.0000	1639	1.0000	4.203	1.0000

Vapour Phase   Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	74.67	0.5335	150.5	0.0918	2.155	0.5126

Nitrogen	34.31	0.2452	961.2	0.5863	1.192	0.2836
Ammonia	30.98	0.2214	527.7	0.3219	0.8565	0.2038
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	140.0	1.0000	1639	1.0000	4.203	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Heat Exchanger: Condenser	Heat Exchanger: E-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

1 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 1 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	25.00	25.00
Pressure: (kPa)	581.3	581.3
Molar Flow (kgmole/h)	61.26	61.26
Mass Flow (kg/h)	1716	1716
Std Ideal Liq VolFlow (m3/h)	2.128	2.128
Molar Enthalpy (kJ/kgmole)	-4.425e+01	-4.425e+01
Molar Entropy (kJ/kgmole-C)	1.334e+02	1.334e+02
Heat Flow (kJ/h)	-2.711e+03	-2.711e+03
Liq VolFlow @Std Cond (m3/h)	1448	1448

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	61.26	1.0000	1716	1.0000	2.128	1.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	61.26	1.0000	1716	1.0000	2.128	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	61.26	1.0000	1716	1.0000	2.128	1.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	61.26	1.0000	1716	1.0000	2.128	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Compressor: K-102		

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

1-2 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 1-2 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	48.89	48.89
Pressure: (kPa)	3300	3300
Molar Flow (kgmole/h)	183.8	183.8
Mass Flow (kg/h)	370.4	370.4
Std Ideal Liq VolFlow (m3/h)	5.303	5.303
Molar Enthalpy (kJ/kgmole)	6.832e+02	6.832e+02
Molar Entropy (kJ/kgmole-C)	9.615e+01	9.615e+01
Heat Flow (kJ/h)	1.255e+05	1.255e+05
Liq VolFlow @Std Cond (m3/h)	4346	4346

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	183.8	1.0000	370.4	1.0000	5.303	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	183.8	1.0000	370.4	1.0000	5.303	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	183.8	1.0000	370.4	1.0000	5.303	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	183.8	1.0000	370.4	1.0000	5.303	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Compressor: K-102-2		

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

2 (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: 2 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	48.61	48.61
Pressure: (kPa)	3411	3411
Molar Flow (kgmole/h)	45.48	45.48
Mass Flow (kg/h)	1455	1455
Std Ideal Liq VolFlow (m3/h)	1.279	1.279
Molar Enthalpy (kJ/kgmole)	4.191e+02	4.191e+02
Molar Entropy (kJ/kgmole-C)	1.173e+02	1.173e+02
Heat Flow (kJ/h)	1.906e+04	1.906e+04
Liq VolFlow @Std Cond (m3/h)	1074	1074

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	45.48	1.0000	1455	1.0000	1.279	1.0000
Total	45.48	1.0000	1455	1.0000	1.279	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	45.48	1.0000	1455	1.0000	1.279	1.0000
Total	45.48	1.0000	1455	1.0000	1.279	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO PRODUCT FROM LOGICAL CONNECTION

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

hydrogen leaving (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments

----

Material Stream: hydrogen leaving Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

OVERALL VAPOUR PH.

Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	74.32	74.32
Pressure: (kPa)	4018	4018
Molar Flow (kgmole/h)	183.8	183.8
Mass Flow (kg/h)	370.4	370.4
Std Ideal Liq VolFlow (m3/h)	5.303	5.303
Molar Enthalpy (kJ/kgmole)	1.415e+03	1.415e+03
Molar Entropy (kJ/kgmole-C)	9.668e+01	9.668e+01
Heat Flow (kJ/h)	2.600e+05	2.600e+05
Liq VolFlow @Std Cond (m3/h)	4346	4346

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	183.8	1.0000	370.4	1.0000	5.303	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	183.8	1.0000	370.4	1.0000	5.303	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	183.8	1.0000	370.4	1.0000	5.303	1.0000
Nitrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	183.8	1.0000	370.4	1.0000	5.303	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO PRODUCT FROM LOGICAL CONNECTION
Compressor: K-102-2
UTILITIES

(No utilities reference this stream)
PROCESS UTILITY

----
leaving nitrogen (Material Stream): Conditions, Composition, K Value, Package Properties, Attachments
----
Material Stream: leaving nitrogen Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (C)	313.7	313.7
Pressure: (kPa)	4100	4100
Molar Flow (kgmole/h)	61.26	61.26
Mass Flow (kg/h)	1716	1716
Std Ideal Liq VolFlow (m3/h)	2.128	2.128
Molar Enthalpy (kJ/kgmole)	8.615e+03	8.615e+03
Molar Entropy (kJ/kgmole-C)	1.374e+02	1.374e+02
Heat Flow (kJ/h)	5.277e+05	5.277e+05
Liq VolFlow @Std Cond (m3/h)	1448	1448

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (kgmole/h)	MOLE FRAC	MASS FLOW (kg/h)	MASS FRAC	LIQVOL FLOW (m3/h)	LIQVOL FRAC
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	61.26	1.0000	1716	1.0000	2.128	1.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	61.26	1.0000	1716	1.0000	2.128	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC

	(kgmole/h)		(kg/h)		(m3/h)	
Hydrogen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nitrogen	61.26	1.0000	1716	1.0000	2.128	1.0000
Ammonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Air	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Propane	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
H2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total	61.26	1.0000	1716	1.0000	2.128	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	---	---	---
Nitrogen	---	---	---
Ammonia	---	---	---
Air	---	---	---
Propane	---	---	---
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
	Compressor: K-102	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

MIX-100 (Mixer): Design, Rating

Mixer: MIX-100

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
1 Hydrogen	
2 Nitrogen	
8-recycle	RCY-1 Recycle

Outlet Stream

STREAM NAME	TO UNIT OPERATION
3	K-100 Compressor

PARAMETERS

User Variables

NOZZLE PARAMETERS

Base Elevation Relative to Ground Level 0.0000 m

	1 Hydrogen	2 Nitrogen	8-recycle
Diameter (m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000	0.0000

	3
Diameter (m)	5.000e-002
Elevation (Base) (m)	0.0000
Elevation (Ground) (m)	0.0000

PFR-100 (Plug Flow Reactor): Design, Rating, Performance

Plug Flow Reactor: PFR-100

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
4a	E-100 Heat Exchanger

Outlet Stream

STREAM NAME	TO UNIT OPERATION
5	E-100 Heat Exchanger

Energy Stream

STREAM NAME	TO UNIT OPERATION

PARAMETERS

Physical Parameters

Type : User Specified Pressure Drop: 14.00 kPa

Heat Transfer

Type : Direct Q Value Energy Stream : Duty : 0.0000 kJ/h

Dimensions

Total Volume: 2.671 m3 Length: 5.766 m Diameter: 0.7680 m Number of Tubes: 1

Wall Thickness: 5.000e-003 m Void Fraction: 1.0000 Void Volume: 2.671 m3

Reaction Info

Reaction Set: Set-1 Initialize From: Current
Integration Information

Number of Segments: 40 Minimum Step Fraction: 1.0e-06 Minimum Step Length: 5.8e-06 m
User Variables

RATING

Sizing

Tube Dimensions
Total Volume 2.671 m3 Length 5.766 m Diameter 0.7680 m Number of Tubes 1 Wall Thickness 5.000e-003 m
Tube Packing
Void Fraction 1.0000 Void Volume 2.671 m3
Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m Diameter 0.7680 m Length 5.766

	5	4a
Diameter (m)	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000

Conditions

Length (m)	Temperature (C)	Pressure (kPa)	Vapour Fraction	Duty (kJ/h)
0.072	676.8	12085.97	1.0000	-0
0.216	676.8	12085.62	1.0000	-0
0.360	676.8	12085.27	1.0000	-0
0.505	676.8	12084.92	1.0000	-0
0.649	676.8	12084.57	1.0000	-0
0.793	676.8	12084.22	1.0000	-0
0.937	676.8	12083.87	1.0000	-0
1.081	676.8	12083.52	1.0000	-0
1.225	676.8	12083.17	1.0000	-0
1.369	676.7	12082.82	1.0000	-0
1.514	676.7	12082.47	1.0000	-0
1.658	676.7	12082.12	1.0000	-0
1.802	676.7	12081.77	1.0000	-0
1.946	676.7	12081.42	1.0000	-0
2.090	676.7	12081.07	1.0000	-0
2.234	676.7	12080.72	1.0000	-0
2.378	676.7	12080.37	1.0000	-0
2.523	676.7	12080.02	1.0000	-0
2.667	676.7	12079.67	1.0000	-0
2.811	676.7	12079.32	1.0000	-0
2.955	676.7	12078.97	1.0000	-0

3.099	676.7	12078.62	1.0000	-0
3.243	676.7	12078.27	1.0000	-0
3.387	676.7	12077.92	1.0000	-0
3.532	676.7	12077.57	1.0000	-0
3.676	676.7	12077.22	1.0000	-0
3.820	676.7	12076.87	1.0000	-0
3.964	676.7	12076.52	1.0000	-0
4.108	676.7	12076.17	1.0000	-0
4.252	676.7	12075.82	1.0000	-0
4.396	676.7	12075.47	1.0000	-0
4.541	676.7	12075.12	1.0000	-0
4.685	676.7	12074.77	1.0000	-0
4.829	676.7	12074.42	1.0000	-0
4.973	676.7	12074.07	1.0000	-0
5.117	676.7	12073.72	1.0000	-0
5.261	676.7	12073.37	1.0000	-0
5.405	676.7	12073.02	1.0000	-0
5.550	676.7	12072.67	1.0000	-0
5.694	676.7	12072.32	1.0000	-0

Length (m)	Enthalpy (kJ/kgmole)	Entropy (kJ/kgmole-C)	Inside HTC (kJ/h-m2-C)	Overall HTC (kJ/h-m2-C)
0.072	11632	146.08	---	---
0.216	11632	146.08	---	---
0.360	11632	146.08	---	---
0.505	11632	146.08	---	---
0.649	11632	146.08	---	---
0.793	11631	146.08	---	---
0.937	11631	146.08	---	---
1.081	11631	146.08	---	---
1.225	11631	146.08	---	---
1.369	11631	146.08	---	---
1.514	11631	146.08	---	---
1.658	11631	146.08	---	---
1.802	11631	146.08	---	---
1.946	11631	146.09	---	---
2.090	11631	146.09	---	---
2.234	11631	146.09	---	---
2.378	11630	146.09	---	---
2.523	11630	146.09	---	---
2.667	11630	146.09	---	---
2.811	11630	146.09	---	---
2.955	11630	146.09	---	---
3.099	11630	146.09	---	---
3.243	11630	146.09	---	---
3.387	11630	146.09	---	---
3.532	11630	146.09	---	---
3.676	11630	146.09	---	---
3.820	11630	146.09	---	---
3.964	11630	146.09	---	---

4.108	11629	146.09	---	---
4.252	11629	146.09	---	---
4.396	11629	146.09	---	---
4.541	11629	146.09	---	---
4.685	11629	146.09	---	---
4.829	11629	146.09	---	---
4.973	11629	146.09	---	---
5.117	11629	146.09	---	---
5.261	11629	146.09	---	---
5.405	11629	146.09	---	---
5.550	11629	146.09	---	---
5.694	11628	146.09	---	---

Flows

Length (m)	Molar Flow (kgmole/h)	Mass Flow (kg/h)	Volumetric Flow (m3/h)	Heat Flow (kJ/h)
0.072	139.958	1639.36	93.740	1.628e+006
0.216	139.958	1639.36	93.742	1.628e+006
0.360	139.958	1639.36	93.744	1.628e+006
0.505	139.958	1639.36	93.747	1.628e+006
0.649	139.958	1639.36	93.749	1.628e+006
0.793	139.959	1639.36	93.752	1.628e+006
0.937	139.959	1639.36	93.754	1.628e+006
1.081	139.959	1639.36	93.756	1.628e+006
1.225	139.959	1639.36	93.759	1.628e+006
1.369	139.959	1639.36	93.761	1.628e+006
1.514	139.959	1639.36	93.764	1.628e+006
1.658	139.959	1639.36	93.766	1.628e+006
1.802	139.959	1639.36	93.768	1.628e+006
1.946	139.959	1639.36	93.771	1.628e+006
2.090	139.959	1639.36	93.773	1.628e+006
2.234	139.960	1639.36	93.776	1.628e+006
2.378	139.960	1639.36	93.778	1.628e+006
2.523	139.960	1639.36	93.781	1.628e+006
2.667	139.960	1639.36	93.783	1.628e+006
2.811	139.960	1639.36	93.785	1.628e+006
2.955	139.960	1639.36	93.788	1.628e+006
3.099	139.960	1639.36	93.790	1.628e+006
3.243	139.960	1639.36	93.793	1.628e+006
3.387	139.960	1639.36	93.795	1.628e+006
3.532	139.960	1639.36	93.797	1.628e+006
3.676	139.960	1639.36	93.800	1.628e+006
3.820	139.961	1639.36	93.802	1.628e+006
3.964	139.961	1639.36	93.805	1.628e+006
4.108	139.961	1639.36	93.807	1.628e+006
4.252	139.961	1639.36	93.809	1.628e+006
4.396	139.961	1639.36	93.812	1.628e+006
4.541	139.961	1639.36	93.814	1.628e+006
4.685	139.961	1639.36	93.817	1.628e+006

4.829	139.961	1639.36	93.819	1.628e+006
4.973	139.961	1639.36	93.822	1.628e+006
5.117	139.961	1639.36	93.824	1.628e+006
5.261	139.962	1639.36	93.826	1.628e+006
5.405	139.962	1639.36	93.829	1.628e+006
5.550	139.962	1639.36	93.831	1.628e+006
5.694	139.962	1639.36	93.834	1.628e+006

Segment Overall Reaction Rates (kgmole/m3-s)

Length (m)	Rxn-1
7.207e-002	5.089e-002
0.2162	-2.012e-007
0.3604	-2.021e-007
0.5045	-2.040e-007
0.6487	-2.021e-007
0.7928	-2.375e-007
0.9369	-2.366e-007
1.081	-2.347e-007
1.225	-2.352e-007
1.369	-2.454e-007
1.514	-2.356e-007
1.658	-2.459e-007
1.802	-2.314e-007
1.946	-2.347e-007
2.090	-2.366e-007
2.234	-2.361e-007
2.378	-2.356e-007
2.523	-2.347e-007
2.667	-2.026e-007
2.811	-1.998e-007
2.955	-2.021e-007
3.099	-2.021e-007
3.243	-2.007e-007
3.387	-2.035e-007
3.532	-1.988e-007
3.676	-2.035e-007
3.820	-2.012e-007
3.964	-2.040e-007
4.108	-2.021e-007
4.252	-2.016e-007
4.396	-2.026e-007
4.541	-2.156e-007
4.685	-2.147e-007
4.829	-2.026e-007
4.973	-2.142e-007
5.117	-2.049e-007
5.261	-2.030e-007
5.405	-2.040e-007
5.550	-2.030e-007

5.694	-2.030e-007

Component Production Rates (kgmole/m3-s)

Length (m)	Hydrogen	Nitrogen	Ammonia	Air
7.207e-002	-0.1527	-5.089e-002	0.1018	0.0000
0.2162	6.035e-007	2.012e-007	-4.023e-007	0.0000
0.3604	6.063e-007	2.021e-007	-4.042e-007	0.0000
0.5045	6.119e-007	2.040e-007	-4.079e-007	0.0000
0.6487	6.063e-007	2.021e-007	-4.042e-007	0.0000
0.7928	7.125e-007	2.375e-007	-4.750e-007	0.0000
0.9369	7.097e-007	2.366e-007	-4.731e-007	0.0000
1.081	7.041e-007	2.347e-007	-4.694e-007	0.0000
1.225	7.055e-007	2.352e-007	-4.703e-007	0.0000
1.369	7.362e-007	2.454e-007	-4.908e-007	0.0000
1.514	7.069e-007	2.356e-007	-4.712e-007	0.0000
1.658	7.376e-007	2.459e-007	-4.917e-007	0.0000
1.802	6.943e-007	2.314e-007	-4.629e-007	0.0000
1.946	7.041e-007	2.347e-007	-4.694e-007	0.0000
2.090	7.097e-007	2.366e-007	-4.731e-007	0.0000
2.234	7.083e-007	2.361e-007	-4.722e-007	0.0000
2.378	7.069e-007	2.356e-007	-4.712e-007	0.0000
2.523	7.041e-007	2.347e-007	-4.694e-007	0.0000
2.667	6.077e-007	2.026e-007	-4.051e-007	0.0000
2.811	5.993e-007	1.998e-007	-3.995e-007	0.0000
2.955	6.063e-007	2.021e-007	-4.042e-007	0.0000
3.099	6.063e-007	2.021e-007	-4.042e-007	0.0000
3.243	6.021e-007	2.007e-007	-4.014e-007	0.0000
3.387	6.105e-007	2.035e-007	-4.070e-007	0.0000
3.532	5.965e-007	1.988e-007	-3.977e-007	0.0000
3.676	6.105e-007	2.035e-007	-4.070e-007	0.0000
3.820	6.035e-007	2.012e-007	-4.023e-007	0.0000
3.964	6.119e-007	2.040e-007	-4.079e-007	0.0000
4.108	6.063e-007	2.021e-007	-4.042e-007	0.0000
4.252	6.049e-007	2.016e-007	-4.033e-007	0.0000
4.396	6.077e-007	2.026e-007	-4.051e-007	0.0000
4.541	6.468e-007	2.156e-007	-4.312e-007	0.0000
4.685	6.440e-007	2.147e-007	-4.293e-007	0.0000
4.829	6.077e-007	2.026e-007	-4.051e-007	0.0000
4.973	6.426e-007	2.142e-007	-4.284e-007	0.0000
5.117	6.147e-007	2.049e-007	-4.098e-007	0.0000
5.261	6.091e-007	2.030e-007	-4.061e-007	0.0000
5.405	6.119e-007	2.040e-007	-4.079e-007	0.0000
5.550	6.091e-007	2.030e-007	-4.061e-007	0.0000
5.694	6.091e-007	2.030e-007	-4.061e-007	0.0000

Length (m)	Propane	H2O	Oxygen
7.207e-002	0.0000	0.0000	0.0000
0.2162	0.0000	0.0000	0.0000
0.3604	0.0000	0.0000	0.0000
0.5045	0.0000	0.0000	0.0000

0.6487	0.0000	0.0000	0.0000
0.7928	0.0000	0.0000	0.0000
0.9369	0.0000	0.0000	0.0000
1.081	0.0000	0.0000	0.0000
1.225	0.0000	0.0000	0.0000
1.369	0.0000	0.0000	0.0000
1.514	0.0000	0.0000	0.0000
1.658	0.0000	0.0000	0.0000
1.802	0.0000	0.0000	0.0000
1.946	0.0000	0.0000	0.0000
2.090	0.0000	0.0000	0.0000
2.234	0.0000	0.0000	0.0000
2.378	0.0000	0.0000	0.0000
2.523	0.0000	0.0000	0.0000
2.667	0.0000	0.0000	0.0000
2.811	0.0000	0.0000	0.0000
2.955	0.0000	0.0000	0.0000
3.099	0.0000	0.0000	0.0000
3.243	0.0000	0.0000	0.0000
3.387	0.0000	0.0000	0.0000
3.532	0.0000	0.0000	0.0000
3.676	0.0000	0.0000	0.0000
3.820	0.0000	0.0000	0.0000
3.964	0.0000	0.0000	0.0000
4.108	0.0000	0.0000	0.0000
4.252	0.0000	0.0000	0.0000
4.396	0.0000	0.0000	0.0000
4.541	0.0000	0.0000	0.0000
4.685	0.0000	0.0000	0.0000
4.829	0.0000	0.0000	0.0000
4.973	0.0000	0.0000	0.0000
5.117	0.0000	0.0000	0.0000
5.261	0.0000	0.0000	0.0000
5.405	0.0000	0.0000	0.0000
5.550	0.0000	0.0000	0.0000
5.694	0.0000	0.0000	0.0000

Transport

Length (m)	Viscosity (cP)	Moleular Weight	Mass Density (kg/m3)	Heat Capacity (kJ/kgmole-C)	Surface Tension (dyne/cm)	Z Factor
7.207e-002	2.839e-002	11.71	17.49	36.566	---	1.025
0.2162	2.839e-002	11.71	17.49	36.566	---	1.025
0.3604	2.839e-002	11.71	17.49	36.566	---	1.025
0.5045	2.839e-002	11.71	17.49	36.566	---	1.025
0.6487	2.839e-002	11.71	17.49	36.566	---	1.025
0.7928	2.839e-002	11.71	17.49	36.566	---	1.025
0.9369	2.839e-002	11.71	17.49	36.566	---	1.025
1.081	2.839e-002	11.71	17.49	36.566	---	1.025
1.225	2.839e-002	11.71	17.48	36.566	---	1.025

1.369	2.839e-002	11.71	17.48	36.566	---	1.025
1.514	2.839e-002	11.71	17.48	36.566	---	1.025
1.658	2.839e-002	11.71	17.48	36.566	---	1.025
1.802	2.839e-002	11.71	17.48	36.565	---	1.025
1.946	2.839e-002	11.71	17.48	36.565	---	1.025
2.090	2.839e-002	11.71	17.48	36.565	---	1.025
2.234	2.839e-002	11.71	17.48	36.565	---	1.025
2.378	2.839e-002	11.71	17.48	36.565	---	1.025
2.523	2.839e-002	11.71	17.48	36.565	---	1.025
2.667	2.839e-002	11.71	17.48	36.565	---	1.025
2.811	2.839e-002	11.71	17.48	36.565	---	1.025
2.955	2.839e-002	11.71	17.48	36.565	---	1.025
3.099	2.839e-002	11.71	17.48	36.565	---	1.025
3.243	2.839e-002	11.71	17.48	36.565	---	1.025
3.387	2.839e-002	11.71	17.48	36.565	---	1.025
3.532	2.839e-002	11.71	17.48	36.565	---	1.025
3.676	2.839e-002	11.71	17.48	36.565	---	1.025
3.820	2.839e-002	11.71	17.48	36.565	---	1.025
3.964	2.839e-002	11.71	17.48	36.565	---	1.025
4.108	2.839e-002	11.71	17.48	36.565	---	1.025
4.252	2.839e-002	11.71	17.48	36.565	---	1.025
4.396	2.839e-002	11.71	17.47	36.565	---	1.025
4.541	2.839e-002	11.71	17.47	36.564	---	1.025
4.685	2.839e-002	11.71	17.47	36.564	---	1.025
4.829	2.839e-002	11.71	17.47	36.564	---	1.025
4.973	2.839e-002	11.71	17.47	36.564	---	1.025
5.117	2.839e-002	11.71	17.47	36.564	---	1.025
5.261	2.839e-002	11.71	17.47	36.564	---	1.025
5.405	2.839e-002	11.71	17.47	36.564	---	1.025
5.550	2.838e-002	11.71	17.47	36.564	---	1.025
5.694	2.838e-002	11.71	17.47	36.564	---	1.025

Component Molar Flowrates (kgmole/h)

Length (m)	Hydrogen	Nitrogen	Ammonia	Air
7.207e-002	74.6605	34.3102	30.9874	0.0000
0.2162	74.6607	34.3102	30.9873	0.0000
0.3604	74.6608	34.3103	30.9872	0.0000
0.5045	74.6609	34.3103	30.9871	0.0000
0.6487	74.6611	34.3104	30.9870	0.0000
0.7928	74.6612	34.3104	30.9869	0.0000
0.9369	74.6614	34.3105	30.9868	0.0000
1.081	74.6615	34.3105	30.9867	0.0000
1.225	74.6617	34.3106	30.9866	0.0000
1.369	74.6618	34.3106	30.9865	0.0000
1.514	74.6620	34.3107	30.9864	0.0000
1.658	74.6621	34.3107	30.9863	0.0000
1.802	74.6622	34.3108	30.9862	0.0000
1.946	74.6624	34.3108	30.9861	0.0000
2.090	74.6625	34.3109	30.9860	0.0000

2.234	74.6627	34.3109	30.9859	0.0000
2.378	74.6628	34.3110	30.9858	0.0000
2.523	74.6630	34.3110	30.9857	0.0000
2.667	74.6631	34.3111	30.9856	0.0000
2.811	74.6633	34.3111	30.9855	0.0000
2.955	74.6634	34.3112	30.9854	0.0000
3.099	74.6635	34.3112	30.9854	0.0000
3.243	74.6637	34.3113	30.9853	0.0000
3.387	74.6638	34.3113	30.9852	0.0000
3.532	74.6640	34.3114	30.9851	0.0000
3.676	74.6641	34.3114	30.9850	0.0000
3.820	74.6643	34.3115	30.9849	0.0000
3.964	74.6644	34.3115	30.9848	0.0000
4.108	74.6646	34.3116	30.9847	0.0000
4.252	74.6647	34.3116	30.9846	0.0000
4.396	74.6648	34.3116	30.9845	0.0000
4.541	74.6650	34.3117	30.9844	0.0000
4.685	74.6651	34.3117	30.9843	0.0000
4.829	74.6653	34.3118	30.9842	0.0000
4.973	74.6654	34.3118	30.9841	0.0000
5.117	74.6656	34.3119	30.9840	0.0000
5.261	74.6657	34.3119	30.9839	0.0000
5.405	74.6659	34.3120	30.9838	0.0000
5.550	74.6660	34.3120	30.9837	0.0000
5.694	74.6662	34.3121	30.9836	0.0000

Length (m)	Propane	H2O	Oxygen
7.207e-002	0.0000	0.0000	0.0000
0.2162	0.0000	0.0000	0.0000
0.3604	0.0000	0.0000	0.0000
0.5045	0.0000	0.0000	0.0000
0.6487	0.0000	0.0000	0.0000
0.7928	0.0000	0.0000	0.0000
0.9369	0.0000	0.0000	0.0000
1.081	0.0000	0.0000	0.0000
1.225	0.0000	0.0000	0.0000
1.369	0.0000	0.0000	0.0000
1.514	0.0000	0.0000	0.0000
1.658	0.0000	0.0000	0.0000
1.802	0.0000	0.0000	0.0000
1.946	0.0000	0.0000	0.0000
2.090	0.0000	0.0000	0.0000
2.234	0.0000	0.0000	0.0000
2.378	0.0000	0.0000	0.0000
2.523	0.0000	0.0000	0.0000
2.667	0.0000	0.0000	0.0000
2.811	0.0000	0.0000	0.0000
2.955	0.0000	0.0000	0.0000
3.099	0.0000	0.0000	0.0000
3.243	0.0000	0.0000	0.0000

3.387	0.0000	0.0000	0.0000
3.532	0.0000	0.0000	0.0000
3.676	0.0000	0.0000	0.0000
3.820	0.0000	0.0000	0.0000
3.964	0.0000	0.0000	0.0000
4.108	0.0000	0.0000	0.0000
4.252	0.0000	0.0000	0.0000
4.396	0.0000	0.0000	0.0000
4.541	0.0000	0.0000	0.0000
4.685	0.0000	0.0000	0.0000
4.829	0.0000	0.0000	0.0000
4.973	0.0000	0.0000	0.0000
5.117	0.0000	0.0000	0.0000
5.261	0.0000	0.0000	0.0000
5.405	0.0000	0.0000	0.0000
5.550	0.0000	0.0000	0.0000
5.694	0.0000	0.0000	0.0000

Component Mole Fractions

Length (m)	Hydrogen	Nitrogen	Ammonia	Air
7.207e-002	0.5334	0.2451	0.2214	0.0000
0.2162	0.5334	0.2451	0.2214	0.0000
0.3604	0.5335	0.2451	0.2214	0.0000
0.5045	0.5335	0.2451	0.2214	0.0000
0.6487	0.5335	0.2451	0.2214	0.0000
0.7928	0.5335	0.2451	0.2214	0.0000
0.9369	0.5335	0.2451	0.2214	0.0000
1.081	0.5335	0.2451	0.2214	0.0000
1.225	0.5335	0.2451	0.2214	0.0000
1.369	0.5335	0.2451	0.2214	0.0000
1.514	0.5335	0.2451	0.2214	0.0000
1.658	0.5335	0.2451	0.2214	0.0000
1.802	0.5335	0.2451	0.2214	0.0000
1.946	0.5335	0.2451	0.2214	0.0000
2.090	0.5335	0.2451	0.2214	0.0000
2.234	0.5335	0.2451	0.2214	0.0000
2.378	0.5335	0.2451	0.2214	0.0000
2.523	0.5335	0.2451	0.2214	0.0000
2.667	0.5335	0.2451	0.2214	0.0000
2.811	0.5335	0.2451	0.2214	0.0000
2.955	0.5335	0.2451	0.2214	0.0000
3.099	0.5335	0.2451	0.2214	0.0000
3.243	0.5335	0.2452	0.2214	0.0000
3.387	0.5335	0.2452	0.2214	0.0000
3.532	0.5335	0.2452	0.2214	0.0000
3.676	0.5335	0.2452	0.2214	0.0000
3.820	0.5335	0.2452	0.2214	0.0000
3.964	0.5335	0.2452	0.2214	0.0000
4.108	0.5335	0.2452	0.2214	0.0000

4.252	0.5335	0.2452	0.2214	0.0000
4.396	0.5335	0.2452	0.2214	0.0000
4.541	0.5335	0.2452	0.2214	0.0000
4.685	0.5335	0.2452	0.2214	0.0000
4.829	0.5335	0.2452	0.2214	0.0000
4.973	0.5335	0.2452	0.2214	0.0000
5.117	0.5335	0.2452	0.2214	0.0000
5.261	0.5335	0.2452	0.2214	0.0000
5.405	0.5335	0.2452	0.2214	0.0000
5.550	0.5335	0.2452	0.2214	0.0000
5.694	0.5335	0.2452	0.2214	0.0000

Length (m)	Propane	H2O	Oxygen
7.207e-002	0.0000	0.0000	0.0000
0.2162	0.0000	0.0000	0.0000
0.3604	0.0000	0.0000	0.0000
0.5045	0.0000	0.0000	0.0000
0.6487	0.0000	0.0000	0.0000
0.7928	0.0000	0.0000	0.0000
0.9369	0.0000	0.0000	0.0000
1.081	0.0000	0.0000	0.0000
1.225	0.0000	0.0000	0.0000
1.369	0.0000	0.0000	0.0000
1.514	0.0000	0.0000	0.0000
1.658	0.0000	0.0000	0.0000
1.802	0.0000	0.0000	0.0000
1.946	0.0000	0.0000	0.0000
2.090	0.0000	0.0000	0.0000
2.234	0.0000	0.0000	0.0000
2.378	0.0000	0.0000	0.0000
2.523	0.0000	0.0000	0.0000
2.667	0.0000	0.0000	0.0000
2.811	0.0000	0.0000	0.0000
2.955	0.0000	0.0000	0.0000
3.099	0.0000	0.0000	0.0000
3.243	0.0000	0.0000	0.0000
3.387	0.0000	0.0000	0.0000
3.532	0.0000	0.0000	0.0000
3.676	0.0000	0.0000	0.0000
3.820	0.0000	0.0000	0.0000
3.964	0.0000	0.0000	0.0000
4.108	0.0000	0.0000	0.0000
4.252	0.0000	0.0000	0.0000
4.396	0.0000	0.0000	0.0000
4.541	0.0000	0.0000	0.0000
4.685	0.0000	0.0000	0.0000
4.829	0.0000	0.0000	0.0000
4.973	0.0000	0.0000	0.0000
5.117	0.0000	0.0000	0.0000
5.261	0.0000	0.0000	0.0000

5.405	0.0000	0.0000	0.0000
5.550	0.0000	0.0000	0.0000
5.694	0.0000	0.0000	0.0000

K-100 (Compressor): Design, Rating, Performance

Compressor: K-100

DESIGN

Connections

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
3	MIX-100 Mixer

Outlet Stream

STREAM NAME	TO UNIT OPERATION
4	E-100 Heat Exchanger

Energy Stream

STREAM NAME	FROM UNIT OPERATION
K100	

Parameters

Speed: --- Duty: 2.0026e+02 kW
Adiabatic Eff.: 75.00 PolyTropic Eff.: 78.45
Adiabatic Head: 3.363e+004 m Polytropic Head: 3.518e+004 m
Adiabatic Fluid Head: 329.8 kJ/kg Polytropic Fluid Head: 345.0 kJ/kg
Polytropic Exp. 1.647 Isentropic Exp. 1.463 Poly Head Factor 0.9978
User Variables

RATING

Curves

Compressor Speed: --- Efficiency: Adiabatic Curves Enabled: Yes
Head Offset: 0.0000 m Efficiency Offset: 0.00 %
Speed:

Flow Head Efficiency (%)
Flow Limits

Surge Curve: Inactive
Speed Flow
Stone Wall Curve: Inactive

Speed Flow

Surge Flow Rate --- Field Flow Rate 102.2 ACT_m3/h Stone Wall Flow --- Compressor Volume 0.0000 m3

Nozzle Paramaters

Base Elevation Relative to Ground Level 0.0000 m

	3	4
Diameter (m)	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000

Inertia

Rotational inertia (kg-m2) 6.000 Radius of gyration (m) 0.2000

Mass (kg) 150.0 Friction loss factor (rad/min) (kg-m2/s) 6.000e-003

PERFORMANCE

Results

Adiabatic Head (m)	3.363e+004	Power Consumed (kW)	200.3
Polytropic Head (m)	3.518e+004	Polytropic Head Factor	0.9978
Adiabatic Fluid Head (kJ/kg)	329.8	Polytropic Exponent	1.647
Polytropic Fluid Head (kJ/kg)	345.0	Isentropic Exponent	1.463
Adiabatic Efficiency	75	Speed (rpm)	---
Polytropic Efficiency	78		---

Power/Torque

Total Rotor Power (kW)	200.3	Total Rotor Torque (N-m)	---
Transient Rotor Power (kW)	0.0000	Transient Rotor Torque (N-m)	---
Friction Power Loss (kW)	0.0000	Friction Torque Loss (N-m)	---
Fluid Power (kW)	200.3	Fluid Torque (N-m)	---

K-101 (Compressor): Design, Rating, Performance

Compressor: K-101

DESIGN

Connections

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
11	Condenser Heat Exchanger

Outlet Stream

STREAM NAME TO UNIT OPERATION

12 Cooler Heat Exchanger
Energy Stream

STREAM NAME FROM UNIT OPERATION
Q Compressor-2
Parameters

Speed: --- Duty: 3.6432e+02 kW
Adiabatic Eff.: 75.00 PolyTropic Eff.: 78.15
Adiabatic Head: 9021 m Polytropic Head: 9399 m
Adiabatic Fluid Head: 88.46 kJ/kg Polytropic Fluid Head: 92.18 kJ/kg
Polytropic Exp. 1.083 Isentropic Exp. 1.034 Poly Head Factor 1.022
User Variables

RATING

Curves

Compressor Speed: --- Efficiency: Adiabatic Curves Enabled: Yes
Head Offset: 0.0000 m Efficiency Offset: 0.00 %
Speed:
Flow Head Efficiency (%)
Flow Limits

Surge Curve: Inactive
Speed Flow
Stone Wall Curve: Inactive
Speed Flow
Surge Flow Rate --- Field Flow Rate 2143 ACT_m3/h Stone Wall Flow --- Compressor Volume 0.0000 m3
Nozzle Paramaters

Base Elevation Relative to Ground Level 0.0000 m

	11	12
Diameter (m)	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000

Inertia

Rotational inertia (kg-m2) 6.000 Radius of gyration (m) 0.2000
Mass (kg) 150.0 Friction loss factor (rad/min) (kg-m2/s) 6.000e-003
PERFORMANCE

Results

Adiabatic Head (m)	9021	Power Consumed (kW)	364.3
Polytropic Head (m)	9399	Polytropic Head Factor	1.022
Adiabatic Fluid Head (kJ/kg)	88.46	Polytropic Exponent	1.083
Polytropic Fluid Head (kJ/kg)	92.18	Isentropic Exponent	1.034

Adiabatic Efficiency 75 Speed (rpm) ---
Polytropic Efficiency 78 ---
Power/Torque

Total Rotor Power (kW) 364.3 Total Rotor Torque (N-m) ---
Transient Rotor Power (kW) 0.0000 Transient Rotor Torque (N-m) ---
Friction Power Loss (kW) 0.0000 Friction Torque Loss (N-m) ---
Fluid Power (kW) 364.3 Fluid Torque (N-m) ---

K-102 (Compressor): Design, Rating, Performance

Compressor: K-102

DESIGN

Connections

Inlet Stream

STREAM NAME FROM UNIT OPERATION
1
Outlet Stream

STREAM NAME TO UNIT OPERATION
leaving nitrogen
Energy Stream

STREAM NAME FROM UNIT OPERATION
K19
Parameters

Speed: --- Duty: 1.4734e+02 kW
Adiabatic Eff.: 75.00 PolyTropic Eff.: 80.48
Adiabatic Head: 2.364e+004 m Polytropic Head: 2.537e+004 m
Adiabatic Fluid Head: 231.8 kJ/kg Polytropic Fluid Head: 248.8 kJ/kg
Polytropic Exp. 1.551 Isentropic Exp. 1.408 Poly Head Factor 0.9995
User Variables

RATING

Curves

Compressor Speed: --- Efficiency: Adiabatic Curves Enabled: Yes
Head Offset: 0.0000 m Efficiency Offset: 0.00 %
Speed:
Flow Head Efficiency (%)

Flow Limits

Surge Curve: Inactive
Speed Flow
Stone Wall Curve: Inactive
Speed Flow
Surge Flow Rate --- Field Flow Rate 260.6 ACT_m3/h Stone Wall Flow --- Compressor Volume 0.0000 m3
Nozzle Paramaters

Base Elevation Relative to Ground Level 0.0000 m

	1	leaving nitrogen
Diameter (m)	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000

Inertia

Rotational inertia (kg-m2) 6.000 Radius of gyration (m) 0.2000
Mass (kg) 150.0 Friction loss factor (rad/min) (kg-m2/s) 6.000e-003
PERFORMANCE

Results

Adiabatic Head (m)	2.364e+004	Power Consumed (kW)	147.3
Polytropic Head (m)	2.537e+004	Polytropic Head Factor	0.9995
Adiabatic Fluid Head (kJ/kg)	231.8	Polytropic Exponent	1.551
Polytropic Fluid Head (kJ/kg)	248.8	Isentropic Exponent	1.408
Adiabatic Efficiency	75	Speed (rpm)	---
Polytropic Efficiency	80		---

Power/Torque

Total Rotor Power (kW)	147.3	Total Rotor Torque (N-m)	---
Transient Rotor Power (kW)	0.0000	Transient Rotor Torque (N-m)	---
Friction Power Loss (kW)	0.0000	Friction Torque Loss (N-m)	---
Fluid Power (kW)	147.3	Fluid Torque (N-m)	---

K-102-2 (Compressor): Design, Rating, Performance

Compressor: K-102-2

DESIGN

Connections

Inlet Stream

STREAM NAME FROM UNIT OPERATION
1-2
Outlet Stream

STREAM NAME TO UNIT OPERATION
hydrogen leaving
Energy Stream

STREAM NAME FROM UNIT OPERATION
K19-2
Parameters

Speed: --- Duty: 3.7347e+01 kW
Adiabatic Eff.: 75.00 PolyTropic Eff.: 75.70
Adiabatic Head: 2.776e+004 m Polytropic Head: 2.802e+004 m
Adiabatic Fluid Head: 272.2 kJ/kg Polytropic Fluid Head: 274.8 kJ/kg
Polytropic Exp. 1.662 Isentropic Exp. 1.438 Poly Head Factor 0.9998
User Variables

RATING

Curves

Compressor Speed: --- Efficiency: Adiabatic Curves Enabled: Yes
Head Offset: 0.0000 m Efficiency Offset: 0.00 %
Speed:
Flow Head Efficiency (%)
Flow Limits

Surge Curve: Inactive
Speed Flow
Stone Wall Curve: Inactive
Speed Flow
Surge Flow Rate --- Field Flow Rate 150.8 ACT_m3/h Stone Wall Flow --- Compressor Volume 0.0000 m3
Nozzle Paramaters

Base Elevation Relative to Ground Level 0.0000 m

	1-2	hydrogen leaving
Diameter (m)	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000

Inertia

Rotational inertia (kg-m2) 6.000 Radius of gyration (m) 0.2000
Mass (kg) 150.0 Friction loss factor (rad/min) (kg-m2/s) 6.000e-003
PERFORMANCE

Results

Adiabatic Head (m) 2.776e+004 Power Consumed (kW) 37.35
Polytropic Head (m) 2.802e+004 Polytropic Head Factor 0.9998
Adiabatic Fluid Head (kJ/kg) 272.2 Polytropic Exponent 1.662
Polytropic Fluid Head (kJ/kg) 274.8 Isentropic Exponent 1.438
Adiabatic Efficiency 75 Speed (rpm) ---
Polytropic Efficiency 76 ---
Power/Torque

Total Rotor Power (kW) 37.35 Total Rotor Torque (N-m) ---
Transient Rotor Power (kW) 0.0000 Transient Rotor Torque (N-m) ---
Friction Power Loss (kW) 0.0000 Friction Torque Loss (N-m) ---
Fluid Power (kW) 37.35 Fluid Torque (N-m) ---

V-100 (Separator): Design, Reactions, Rating, Carry Over

Separator: V-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
6	Heat Exchanger: Condenser

Outlet Stream

Stream Name	To Unit Operation
7	Recycle: RCY-1
9	

Energy Stream

Stream Name	From Unit Operation

PARAMETERS

Vessel Volume: --- Level SP: 50.00 % Liquid Volume: ---
Vessel Pressure: 4017 kPa Pressure Drop: 8000 kPa Duty: 0.0000 kJ/h Heat Transfer Mode: Heating
User Variables

RATING

Sizing

Cylinder Vertical Separator has a Boot: No
Volume: --- Diameter: --- Height: ---
Nozzles

Base Elevation Relative to Ground Level 0.0000 m Diameter --- Height ---

	6	7	9
Diameter (m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000	0.0000
Elevation (% of Height) (%)	---	---	---

Level Taps: Level Tap Specification

Level Tap	PV High	PV Low	OP High	OP Low

Level Taps: Calculated Level Tap Values

Level Tap	Liquid Level	Aqueous Level

Options

PV Work Term Contribution (%) 100.00

RCY-1 (Recycle): Design

Recycle: RCY-1

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
7	V-100 Separator

Outlet Stream

Stream Name	To Unit Operation
8-recycle	MIX-100 Mixer

TOLERANCE

Vapour Fraction: 10.00 Temperature: 10.00 Pressure: 10.00
Flow: 10.00 Enthalpy: 10.00 Composition: 10.00

NUMERICAL

Acceleration Type: Wegstein Iteration Type: Nested
Maximum Iterations: 10 Iteration Count: 0
Wegstein Count: 3 Q Minimum: -20.00 Q Maximum: 0.0000

Iteration History

Iteration	Variable	Outlet Value	Inlet Value
0	Converged	---	---

User Variables

Condenser (Heat Exchanger): Design, Rating, Details, Tables, HTFS Results, Exchanger Design and Rating

----

Heat Exchanger: Condenser

CONNECTIONS

Tube Side Shell Side

Inlet		Outlet		Inlet		Outlet	
Name	5a	Name	6	Name	10	Name	11
From Op.	E-100	To Op.	V-100	From Op.	VLV-101-2	To Op.	K-101
Op. Type	Heat Exchanger	Op. Type	Separator	Op. Type	Valve	Op. Type	Compressor
Temp	432.61 C	Temp	-10.00 C	Temp	-20.00 C	Temp	-18.00 C

PARAMETERS

Heat Exchanger Model: Simple End Point

Tube Side DeltaP: 40.00 kPa Shell Side DeltaP: 9.807 kPa Passes: ---

UA: 2.276e+004 kJ/C-h Tolerance: 1.0000e-04

Tube Side Data		Shell Side Data	
Heat Transfer Coeff	---	Heat Transfer Coeff	---
Tube Pressure Drop	40.00 kPa	Shell Pressure Drop	9.81 kPa
Fouling	0.00000 C-h-m2/kJ	Fouling	0.00000 C-h-m2/kJ
Tube Length	6.00 m	Shell Passes	1
Tube O.D.	20.00 mm	Shell Series	1
Tube Thickness	2.0000 mm	Shell Parallel	1
Tube Pitch	50.0000 mm	Baffle Type	Single
Orientation	Horizontal	Baffle Cut(%Area)	20.00
Passes Per Shell	2	Baffle Orientation	Horizontal
Tubes Per Shell	160	Spacing	800.0000 mm
Layout Angle	Triangular (30 degrees)	Diameter	739.0488 mm
TEMA Type	A E L	Area	60.32 m2

SPECS

	Spec Value	Curr Value	Rel Error	Active	Estimate
E-102 Heat Balance	0.0000 kJ/h	-6.192 kJ/h	-2.379e-006	On	Off
E-102 UA	---	2.276e+004 kJ/C-h	---	On	Off

Detailed Specifications

E-102 Heat Balance

Type: Duty Pass: Error Spec Value: 0.0000 kJ/h

E-102 UA

Type: UA Pass: Overall Spec Value: ---

User Variables

RATING

Sizing

Overall Data

Configuration

# of Shells in Series 1	Tube Passes per Shell 2	Elevation (Base) 0.0000 m
# of Shells in Parallel 1	Exchange Orientation Horizontal	First Tube Pass Flow Direction Counter
TEMA Type: A	E	L

Calculated Information

Shell HT Coeff ---	Tube HT Coeff ---
Overall U 377.4 kJ/h-m2-C	Overall UA 2.276e+004 kJ/C-h
Shell DP 9.807 kPa	Tube DP 40.00 kPa
Shell Vol per Shell 2.272 m3	Tube Vol per Shell 0.1930 m3
HT Area per Shell 60.32 m2	

Shell Data

Shell and Tube Bundle

Shell Diameter 739.0 (mm)	Tube Pitch 50.00 (mm)	Shell Fouling 0.0000 (C-h-m2/kJ)

# of Tubes per Shell 160	Tube Layout Angle Triangular (30 degrees)

Shell Baffles

Shell Baffle Type Single	Shell Baffle Orientation Horizontal
Baffle Cut (%Area) 20.00	Baffle Spacing 800.0 mm

Tube Data

Dimensions

OD 20.00 (mm)	ID 16.00 (mm)	Tube Thickness 2.000 (mm)	Tube Length 6.000 (m)

Tube Properties

Tube Fouling 0.0000 (C-h-m2/kJ)	Thermal Cond. 45.00 (W/m-K)	Wall Cp --- (kJ/kg-C)	Wall Density --- (kg/m3)

Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m

	5a	10	6
Diameter (m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000	0.0000
Elevation (% of Height) (%)	0.00	0.00	0.00

	11
Diameter (m)	5.000e-002
Elevation (Base) (m)	0.0000
Elevation (Ground) (m)	0.0000
Elevation (% of Height) (%)	0.00

DETAILS

Overall/Detailed Performance

Duty: 2.603e+06 kJ/h UA Curv. Error: 0.00e-01 kJ/C-h

Heat Leak: 0.000e-01 kJ/h
Hot Pinch Temp: -10.00 C
Heat Loss: 0.000e-01 kJ/h
Cold Pinch Temp: -20.00 C
UA: 2.276e+04 kJ/C-h
Ft Factor: ---
Min. Approach: 10.00 C
Uncorrected Lmtd: 117.0 C
Lmtd: 114.3 C

TABLES

Shell Side - Overall Phase

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)
-20.00	244.17	0.00	-117593.30
-21.11	234.57	2549200.06	-107483.87
-18.00	234.37	2602960.45	-107270.67

UA (kJ/C-h)	Molar Vap Frac	Mass Vap Frac	Heat of Vap. (kJ/kgmole)
0.00	0.4259	0.4259	---
0.00	1.0000	1.0000	---
0.00	1.0000	1.0000	---

Shell Side - Vapour Phase

Mass Flow (kg/h)	Molecular Wt	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)
4736.03	44.10	5.47	1.55	0.01	0.01
11119.53	44.10	5.27	1.54	0.01	0.01
11119.53	44.10	5.19	1.56	0.01	0.01

Std Gas Flow (STD_m3/h)	Z Factor	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	0.93	4256.66	96.75	0.28	0.15
---	0.94	4256.66	96.75	0.28	0.15
---	0.94	4256.66	96.75	0.28	0.15

Shell Side - Light Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
6383.50	554.85	2.35	0.16	0.12	12.51
0.00	556.23	2.34	0.16	0.12	12.66
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
44.10	0.55	4256.66	96.75	0.28	0.15
44.10	0.56	4256.66	96.75	0.28	0.15
---	---	---	---	---	---

Shell Side - Heavy Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
---	---	---	---	---	---
---	---	---	---	---	---

---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---

Shell Side - Mixed Liquid

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
6383.50	554.85	2.35	0.16	0.12	---
0.00	556.23	2.34	0.16	0.12	---
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
44.10	0.55	4256.66	96.75	0.28	0.15
44.10	0.56	4256.66	96.75	0.28	0.15
---	---	---	---	---	---

Tube Side - Overall Phase

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)
-10.00	12017.32	0.00	-15666.77
45.14	12029.09	765569.45	-10196.93
432.61	12057.32	2602966.65	2930.91

UA (kJ/C-h)	Molar Vap Frac	Mass Vap Frac	Heat of Vap. (kJ/kgmole)
0.00	0.8103	0.7254	---
0.00	1.0000	1.0000	---
0.00	1.0000	1.0000	---

Tube Side - Vapour Phase

Mass Flow (kg/h)	Molecular Wt	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)
1189.15	10.48	56.60	3.02	0.01	0.09
1639.36	11.71	54.84	2.97	0.01	0.09
1639.36	11.71	23.43	2.96	0.02	0.16

Std Gas Flow (STD_m3/h)	Z Factor	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
2681.63	1.02	2351.44	-196.45	0.30	-0.06
3309.32	0.97	4030.31	-134.60	0.29	0.00
3309.32	1.03	4030.31	-134.60	0.29	0.00

Tube Side - Light Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
450.21	643.07	4.52	0.18	0.55	34.03
0.00	559.42	5.18	0.09	0.42	20.86
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
16.96	0.64	11202.86	129.66	0.27	0.25
16.88	0.56	11102.00	125.94	0.27	0.25
---	---	---	---	---	---

Tube Side - Heavy Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---

Tube Side - Mixed Liquid

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
450.21	643.07	4.52	0.18	0.55	---
0.00	559.42	5.18	0.09	0.42	---
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
16.96	0.64	11202.86	129.66	0.27	0.25
16.88	0.56	11102.00	125.94	0.27	0.25
---	---	---	---	---	---

HTFS

Exchanger Design and Rating

Cooler (Heat Exchanger): Design, Rating, Details, Tables, HTFS Results, Exchanger Design and Rating

----

Heat Exchanger: Cooler

CONNECTIONS

Tube Side				Shell Side			
Inlet		Outlet		Inlet		Outlet	
Name	14-cw inlet	Name	15 - cw outlet	Name	12	Name	13

From Op. To Op. From Op. K-101 To Op. VLV-101-2
Op. Type Op. Type Op. Type Compressor Op. Type Valve
Temp 25.00 C Temp 42.00 C Temp 68.24 C Temp 43.60 C
PARAMETERS

Heat Exchanger Model: Simple End Point

Tube Side DeltaP: 98.07 kPa Shell Side DeltaP: 9.807 kPa Passes: ---
UA: 2.109e+005 kJ/C-h Tolerance: 1.0000e-04

Tube Side Data		Shell Side Data	
Heat Transfer Coeff	---	Heat Transfer Coeff	---
Tube Pressure Drop	98.07 kPa	Shell Pressure Drop	9.81 kPa
Fouling	0.00000 C-h-m2/kJ	Fouling	0.00000 C-h-m2/kJ
Tube Length	6.00 m	Shell Passes	1
Tube O.D.	20.00 mm	Shell Series	1
Tube Thickness	2.0000 mm	Shell Parallel	1
Tube Pitch	50.0000 mm	Baffle Type	Single
Orientation	Horizontal	Baffle Cut(%Area)	20.00
Passes Per Shell	2	Baffle Orientation	Horizontal
Tubes Per Shell	160	Spacing	800.0000 mm
Layout Angle	Triangular (30 degrees)	Diameter	739.0488 mm
TEMA Type	A E L	Area	60.32 m2

SPECS

	Spec Value	Curr Value	Rel Error	Active	Estimate
E-103 Heat Balance	0.0000 kJ/h	-1.504e-006 kJ/h	-3.843e-013	On	Off
E-103 UA	---	2.109e+005 kJ/C-h	---	On	Off

Detailed Specifications

E-103 Heat Balance
Type: Duty Pass: Error Spec Value: 0.0000 kJ/h
E-103 UA
Type: UA Pass: Overall Spec Value: ---
User Variables

RATING

Sizing

Overall Data
Configuration
# of Shells in Series 1 Tube Passes per Shell 2 Elevation (Base) 0.0000 m
# of Shells in Parallel 1 Exchange Orientation Horizontal First Tube Pass Flow Direction Counter
TEMA Type: A E L
Calculated Information
Shell HT Coeff --- Tube HT Coeff ---
Overall U 3496 kJ/h-m2-C Overall UA 2.109e+005 kJ/C-h
Shell DP 9.807 kPa Tube DP 98.07 kPa
Shell Vol per Shell 2.272 m3 Tube Vol per Shell 0.1930 m3

HT Area per Shell 60.32 m2
Shell Data
Shell and Tube Bundle

Shell Diameter 739.0 (mm)	Tube Pitch 50.00 (mm)	Shell Fouling 0.0000 (C-h-m2/kJ)

# of Tubes per Shell 160 Tube Layout Angle Triangular (30 degrees)
Shell Baffles
Shell Baffle Type Single Shell Baffle Orientation Horizontal
Baffle Cut (%Area) 20.00 Baffle Spacing 800.0 mm
Tube Data
Dimensions

OD 20.00	ID 16.00	Tube Thickness 2.000	Tube Length 6.000
(mm)	(mm)	(mm)	(m)

Tube Properties

Tube Fouling 0.0000	Thermal Cond. 45.00	Wall Cp ---	Wall Density ---
(C-h-m2/kJ)	(W/m-K)	(kJ/kg-C)	(kg/m3)

Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m

	14-cw inlet	12	15 - cw outlet
Diameter (m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000	0.0000
Elevation (% of Height) (%)	0.00	0.00	0.00

	13
Diameter (m)	5.000e-002
Elevation (Base) (m)	0.0000
Elevation (Ground) (m)	0.0000
Elevation (% of Height) (%)	0.00

DETAILS

Overall/Detailed Performance

Duty: 3.915e+06 kJ/h UA Curv. Error: 0.00e-01 kJ/C-h
Heat Leak: 0.000e-01 kJ/h Hot Pinch Temp: 43.60 C
Heat Loss: 0.000e-01 kJ/h Cold Pinch Temp: 25.00 C
UA: 2.109e+05 kJ/C-h Ft Factor: ---
Min. Approach: 18.60 C Uncorrected Lmtd: 22.20 C
Lmtd: 18.56 C
TABLES

Shell Side - Overall Phase

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)
43.60	1491.52	0.00	-117593.30
43.85	1499.89	3340694.72	-104345.02
68.24	1501.32	3914508.78	-102069.43
UA	Molar Vap Frac	Mass Vap Frac	Heat of Vap.

(kJ/C-h)			(kJ/kgmole)
0.00	0.0000	0.0000	---
0.00	1.0000	1.0000	---
0.00	1.0000	1.0000	---

Shell Side - Vapour Phase

Mass Flow (kg/h)	Molecular Wt	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)
0.00	44.10	33.26	2.13	0.01	0.02
11119.53	44.10	33.47	2.13	0.01	0.02
11119.53	44.10	28.81	2.12	0.01	0.02

Std Gas Flow (STD_m3/h)	Z Factor	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
0.00	0.75	4256.66	96.75	0.28	0.15
5962.20	0.75	4256.66	96.75	0.28	0.15
5962.20	0.81	4256.66	96.75	0.28	0.15

Shell Side - Light Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
11119.53	461.16	3.21	0.08	0.08	4.78
0.00	460.71	3.21	0.08	0.08	4.75
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
44.10	0.46	4256.66	96.75	0.28	0.15
44.10	0.46	4256.66	96.75	0.28	0.15
---	---	---	---	---	---

Shell Side - Heavy Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	---	---	---	---	---
---	---	---	---	---	---
---	---	---	---	---	---

Shell Side - Mixed Liquid

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
11119.53	461.16	3.21	0.08	0.08	---
0.00	460.71	3.21	0.08	0.08	---
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega

44.10	0.46	4256.66	96.75	0.28	0.15
44.10	0.46	4256.66	96.75	0.28	0.15
---	---	---	---	---	---

Tube Side - Overall Phase

Temperature	Pressure	Heat Flow	Enthalpy
(C)	(kPa)	(kJ/h)	(kJ/kgmole)
25.00	202.32	0.00	-286218.97
42.00	104.26	3914508.78	-284899.34
UA	Molar Vap Frac	Mass Vap Frac	Heat of Vap.
(kJ/C-h)			(kJ/kgmole)
0.00	0.0000	0.0000	---
0.00	0.0000	0.0000	---

Tube Side - Vapour Phase

Mass Flow	Molecular Wt	Density	Mass Sp Heat	Viscosity	Thermal Cond
(kg/h)		(kg/m3)	(kJ/kg-C)	(cP)	(W/m-K)
---	---	---	---	---	---
---	---	---	---	---	---
Std Gas Flow	Z Factor	Pseudo Pc	Pseudo Tc	Pseudo Zc	Pseudo Omega
(STD_m3/h)		(kPa)	(C)		
---	---	---	---	---	---
---	---	---	---	---	---

Tube Side - Light Liquid Phase

Mass Flow	Density	Mass Sp Heat	Viscosity	Thermal Cond	Surface Tens
(kg/h)	(kg/m3)	(kJ/kg-C)	(cP)	(W/m-K)	(dyne/cm)
---	---	---	---	---	---
---	---	---	---	---	---
Molecular Wt	Sp Gravity	Pseudo Pc	Pseudo Tc	Pseudo Zc	Pseudo Omega
		(kPa)	(C)		
---	---	---	---	---	---
---	---	---	---	---	---

Tube Side - Heavy Liquid Phase

Mass Flow	Density	Mass Sp Heat	Viscosity	Thermal Cond	Surface Tens
(kg/h)	(kg/m3)	(kJ/kg-C)	(cP)	(W/m-K)	(dyne/cm)
53439.45	1007.37	4.31	0.89	0.61	72.10
53439.45	994.42	4.32	0.63	0.63	69.14
Molecular Wt	Sp Gravity	Pseudo Pc	Pseudo Tc	Pseudo Zc	Pseudo Omega
		(kPa)	(C)		
18.02	1.01	22120.00	374.15	0.26	0.34
18.02	0.99	22120.00	374.15	0.26	0.34

Tube Side - Mixed Liquid

Mass Flow	Density	Mass Sp Heat	Viscosity	Thermal Cond	Surface Tens
(kg/h)	(kg/m3)	(kJ/kg-C)	(cP)	(W/m-K)	(dyne/cm)
53439.45	1007.37	4.31	0.89	0.61	---
53439.45	994.42	4.32	0.63	0.63	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
18.02	1.01	22120.00	374.15	0.26	0.34
18.02	0.99	22120.00	374.15	0.26	0.34

HTFS

Exchanger Design and Rating

E-100 (Heat Exchanger): Design, Rating, Details, Tables, HTFS Results, Exchanger Design and Rating

----

Heat Exchanger: E-100

CONNECTIONS

Tube Side		Shell Side	
Inlet	Outlet	Inlet	Outlet
Name 4	Name 4a	Name 5	Name 5a
From Op. K-100	To Op. PFR-100	From Op. PFR-100	To Op. Condenser
Op. Type Compressor	Op. Type Plug Flow Reactor	Op. Type Plug Flow Reactor	Op. Type Heat Exchanger
Temp 173.18 C	Temp 415.00 C	Temp 676.65 C	Temp 432.61 C

PARAMETERS

Heat Exchanger Model: Simple End Point

Tube Side DeltaP: 15.00 kPa Shell Side DeltaP: 15.00 kPa Passes: ---

UA: 5610 kJ/C-h Tolerance: 1.0000e-04

Tube Side Data		Shell Side Data	
Heat Transfer Coeff	---	Heat Transfer Coeff	---
Tube Pressure Drop	15.00 kPa	Shell Pressure Drop	15.00 kPa
Fouling	0.00000 C-h-m2/kJ	Fouling	0.00000 C-h-m2/kJ
Tube Length	6.00 m	Shell Passes	1
Tube O.D.	20.00 mm	Shell Series	1
Tube Thickness	2.0000 mm	Shell Parallel	1
Tube Pitch	50.0000 mm	Baffle Type	Single
Orientation	Horizontal	Baffle Cut(%Area)	20.00
Passes Per Shell	2	Baffle Orientation	Horizontal
Tubes Per Shell	160	Spacing	800.0000 mm
Layout Angle	Triangular (30 degrees)	Diameter	739.0488 mm
TEMA Type	A E L	Area	60.32 m2

SPECS

	Spec Value	Curr Value	Rel Error	Active	Estimate
E-100 Heat Balance	0.0000 kJ/h	2.046e-010 kJ/h	1.681e-016	On	Off
E-100 UA	---	5610 kJ/C-h	---	On	Off

Detailed Specifications

E-100 Heat Balance

Type: Duty Pass: Error Spec Value: 0.0000 kJ/h

E-100 UA

Type: UA Pass: Overall Spec Value: ---

User Variables

RATING

Sizing

Overall Data

Configuration

# of Shells in Series 1 Tube Passes per Shell 2 Elevation (Base) 0.0000 m

# of Shells in Parallel 1 Exchange Orientation Horizontal First Tube Pass Flow Direction Counter

TEMA Type: A E L

Calculated Information

Shell HT Coeff --- Tube HT Coeff ---

Overall U 93.00 kJ/h-m2-C Overall UA 5610 kJ/C-h

Shell DP 15.00 kPa Tube DP 15.00 kPa

Shell Vol per Shell 2.272 m3 Tube Vol per Shell 0.1930 m3

HT Area per Shell 60.32 m2

Shell Data

Shell and Tube Bundle

Shell Diameter 739.0 (mm) Tube Pitch 50.00 (mm) Shell Fouling 0.0000 (C-h-m2/kJ)

# of Tubes per Shell 160 Tube Layout Angle Triangular (30 degrees)

Shell Baffles

Shell Baffle Type Single Shell Baffle Orientation Horizontal

Baffle Cut (%Area) 20.00 Baffle Spacing 800.0 mm

Tube Data

Dimensions

OD 20.00 (mm) ID 16.00 (mm) Tube Thickness 2.000 (mm) Tube Length 6.000 (m)

Tube Properties

Tube Fouling 0.0000 (C-h-m2/kJ) Thermal Cond. 45.00 (W/m-K) Wall Cp --- (kJ/kg-C) Wall Density --- (kg/m3)

Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m

	4	5	4a
Diameter (m)	5.000e-002	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000	0.0000
Elevation (% of Height) (%)	0.00	0.00	0.00

5a

Diameter (m) 5.000e-002
Elevation (Base) (m) 0.0000
Elevation (Ground) (m) 0.0000
Elevation (% of Height) (%) 0.00
DETAILS

Overall/Detailed Performance

Duty: 1.217e+06 kJ/h UA Curv. Error: 0.00e-01 kJ/C-h
Heat Leak: 0.000e-01 kJ/h Hot Pinch Temp: 432.6 C
Heat Loss: 0.000e-01 kJ/h Cold Pinch Temp: 173.2 C
UA: 5.610e+03 kJ/C-h Ft Factor: ---
Min. Approach: 259.4 C Uncorrected Lmtd: 260.5 C
Lmtd: 217.0 C
TABLES

Shell Side - Overall Phase

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)
432.61	12057.32	0.00	2930.91
676.65	12072.32	1217324.73	11628.46

UA (kJ/C-h)	Molar Vap Frac	Mass Vap Frac	Heat of Vap. (kJ/kgmole)
0.00	1.0000	1.0000	---
0.00	1.0000	1.0000	---

Shell Side - Vapour Phase

Mass Flow (kg/h)	Molecular Wt	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)
1639.36	11.71	23.43	2.96	0.02	0.16
1639.36	11.71	17.47	3.12	0.03	0.20

Std Gas Flow (STD_m3/h)	Z Factor	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
3309.32	1.03	4030.31	-134.60	0.29	0.00
3309.32	1.02	4030.31	-134.60	0.29	0.00

Shell Side - Light Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
---	---	---	---	---	---
0.00	17.48	3.12	0.01	0.10	0.00

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	---	---	---	---	---
11.72	0.02	4039.04	-134.27	0.29	0.00

Shell Side - Heavy Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
---	---	---	---	---	---
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	---	---	---	---	---
---	---	---	---	---	---

Shell Side - Mixed Liquid

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
---	---	---	---	---	---
0.00	17.48	3.12	0.01	0.10	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	---	---	---	---	---
11.72	0.02	4039.04	-134.27	0.29	0.00

Tube Side - Overall Phase

Temperature (C)	Pressure (kPa)	Heat Flow (kJ/h)	Enthalpy (kJ/kgmole)
173.18	12101.32	0.00	2497.50
415.00	12086.32	1217324.73	9900.94

UA (kJ/C-h)	Molar Vap Frac	Mass Vap Frac	Heat of Vap. (kJ/kgmole)
0.00	1.0000	1.0000	---
0.00	1.0000	1.0000	---

Tube Side - Vapour Phase

Mass Flow (kg/h)	Molecular Wt	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)
1639.37	9.97	31.32	3.05	0.02	0.14
1639.37	9.97	20.41	3.11	0.02	0.18

Std Gas Flow (STD_m3/h)	Z Factor	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
3887.78	1.04	2298.87	-198.70	0.30	-0.06
3887.78	1.03	2298.87	-198.70	0.30	-0.06

Tube Side - Light Liquid Phase

Mass Flow (kg/h)	Density (kg/m3)	Mass Sp Heat (kJ/kg-C)	Viscosity (cP)	Thermal Cond (W/m-K)	Surface Tens (dyne/cm)
---	---	---	---	---	---
---	---	---	---	---	---

Molecular Wt	Sp Gravity	Pseudo Pc (kPa)	Pseudo Tc (C)	Pseudo Zc	Pseudo Omega
---	---	---	---	---	---
---	---	---	---	---	---

Tube Side - Heavy Liquid Phase

Mass Flow Density Mass Sp Heat Viscosity Thermal Cond Surface Tens
(kg/h) (kg/m3) (kJ/kg-C) (cP) (W/m-K) (dyne/cm)

---	---	---	---	---	---
---	---	---	---	---	---

Molecular Wt Sp Gravity Pseudo Pc Pseudo Tc Pseudo Zc Pseudo Omega
(kPa) (C)

---	---	---	---	---	---
---	---	---	---	---	---

Tube Side - Mixed Liquid

Mass Flow Density Mass Sp Heat Viscosity Thermal Cond Surface Tens
(kg/h) (kg/m3) (kJ/kg-C) (cP) (W/m-K) (dyne/cm)

---	---	---	---	---	---
---	---	---	---	---	---

Molecular Wt Sp Gravity Pseudo Pc Pseudo Tc Pseudo Zc Pseudo Omega
(kPa) (C)

---	---	---	---	---	---
---	---	---	---	---	---

HTFS

Exchanger Design and Rating

VLV-101-2 (Valve): Design, Rating

Valve: VLV-101-2

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
13	Cooler Heat Exchanger

Outlet Stream

STREAM NAME	TO UNIT OPERATION
10	Condenser Heat Exchanger

PARAMETERS

Physical Properties

Pressure Drop: 1247 kPa
User Variables

RATING

Sizing

Sizing Conditions
Inlet Pressure 1492 kPa Molecular Weight 44.10 Current
Valve Opening 50.00 % Delta P 1247 kPa Flow Rate 1.112e+004 kg/h
Valve Sizing Method and Type
Sizing Method: ANSI/ISA
Valve Operating Characteristic and Sizing Information
Linear Sized Coefficient: Cv (standard) cal/min.sqrt(psi)
Fl 0.9000 Cv 10.73 USGPM(60F,1psi) Cg 359.0 Fp 1.000 Xt 0.7000 Rigorous Cp/Cv Method
Nozzle Parameters

Base Elevation Relative to Ground Level 0.0000 m

	13	10
Diameter (m)	5.000e-002	5.000e-002
Elevation (Base) (m)	0.0000	0.0000
Elevation (Ground) (m)	0.0000	0.0000
Elevation (% of Height) (%)		

Aspen Technology Inc. Aspen HYSYS Version 10