Letter of Transmittal

Date: April 2, 2020

To: AIChE Representatives

Managers of Senior Design Group

From: AIChE Competition Design Group #14

Subject: AIChE 2019-2020 Student Design Competition:

"Green" Ammonia Production

In response to the project statement as proposed by the American Institute of Chemical Engineers, our team has developed a feasible and stable process capable of producing ammonia while operating under the specified project parameters.

The aforementioned AIChE Project was posed to the senior ChE students on February 3rd, 2020. This project tasked our team with designing an anhydrous ammonia production plant, emphasizing the practicality of utilization of "green," or environmentally friendly practices. Additionally the project asked students to realistically detail the theoretical construction and subsequent 20 year operation of the plant.

Through our research, calculations, and in-depth analysis our team feels confident in the results of our design for an eco-friendly alternative to the standard gas-fueled, greenhouse gas producing, large-scale ammonia production process.

We hope you find our decisions, findings, and analysis report helpful and enlightening.

Thank you,

Group #14

CHE 4224

Spring 2020

AIChE National Student Design Competition

Modular Distributed Ammonia Synthesis

April 2, 2020

Group Number 14

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Abstract

Anhydrous ammonia production through eco-conscious production methods was the driving force behind this project. Another important factor of the design was to locate it within the Midwest to lower transportation costs and emissions for this versatile product. Two reactants are required to produce the required amount of ammonia, these would be hydrogen and nitrogen gases.

To produce anhydrous ammonia, we first have to procure the reactants. Hydrogen was able to be separated from oxygen within water molecules through an Alkaline Electrolyzer. The nitrogen is simultaneously extracted from ambient air through a Pressure Swing Adsorber. These two components then mix gaseous streams and undergo the Haber-Bosch process to create 50 tons of ammonia per day, where it is then chilled for cold storage. The site was able to meet the production demands using hybrid modular design with minimal carbon footprint, and facility size. The plant is not profitable under the current design, due to capital and operating costs exceeding revenues produced from anhydrous ammonia and oxygen gas products. The team would not recommend pursuing the project.

Introduction

The American Institute of Chemical Engineers has given the task of creating an ammonia plant in the Minnesota River Valley. Groups have the goal to design a plant capable of producing 50 metric tons of anhydrous ammonia per day and determine if the plant designs are profitable. The provided design project packet explained potential alternatives to design both the upstream and downstream processes of the project, but did not limit the design decisions to any of the options offered. Emphasis on modular "green" designs were specified.

A large portion of the American ammonia production is used for fertilizer in the agriculture market. The traditional method of ammonia production requires natural gas and produces hydrocarbon byproducts. With today's understanding of greenhouse gases, it is imperative to find sustainable solutions. The majority of ammonia is currently produced in the gulf coast, near oil refineries, and shipped to the Midwest. Developing an ammonia production facility in the Midwest both limits transportation liability, and allows the advantageous use of renewable energy sources to minimize expenses and secure profits. The Minnesota River Valley has an abundant amount of wind. The power required to run the plant would ideally be sourced from clean energy wind farms. These wind farms could be developed in response to the industrial demand brought by this plant.

Anhydrous ammonia can be used as agricultural fertilizer by injecting the liquid into the ground, where it then vaporizes and absorbs into the soil. This ammonia is produced from the reaction of hydrogen (H_2) and nitrogen (N_2) gases, in the presence of a metal catalyst at a high temperature and pressure. The hydrogen can be sourced from the electrolysis of water, while the nitrogen can be separated from ambient air with a Pressure Swing Adsorber.

Process Flow Diagram and Material Balances

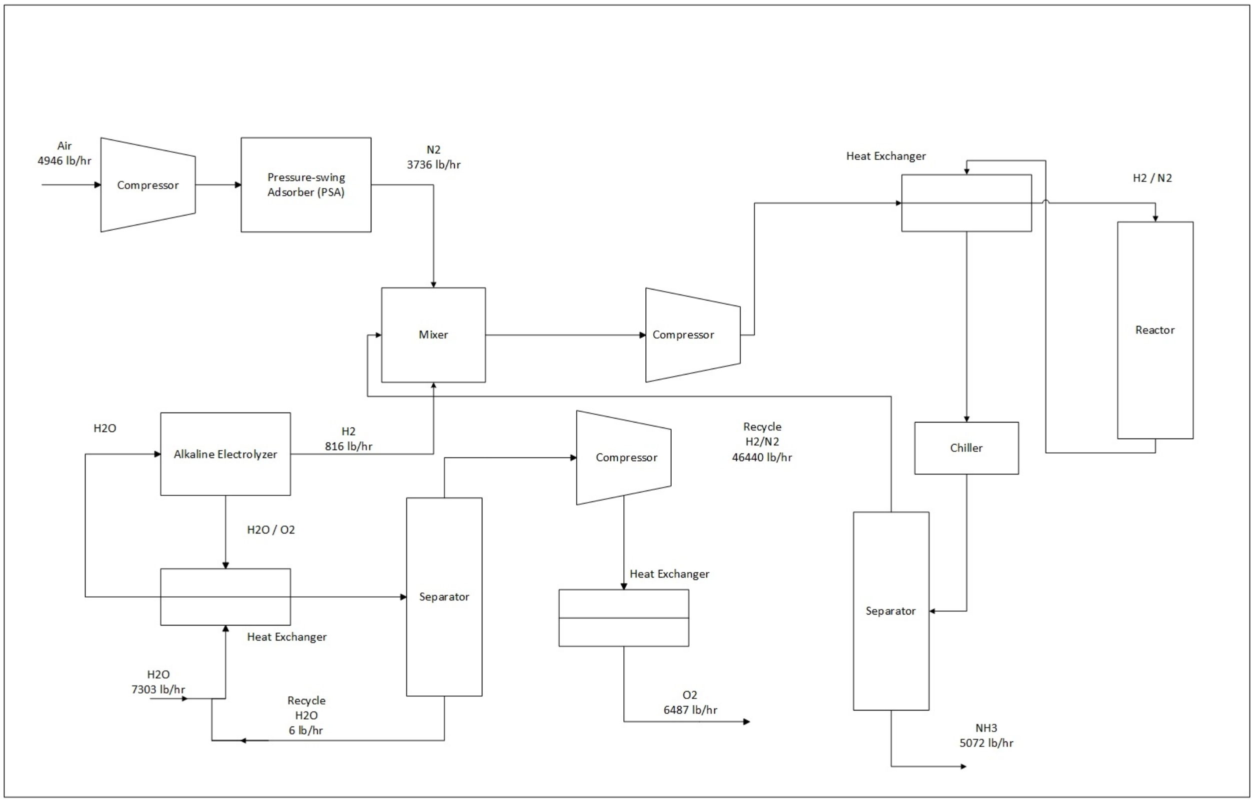

Figure 1: Ammonia Synthesis Block Flow Diagram

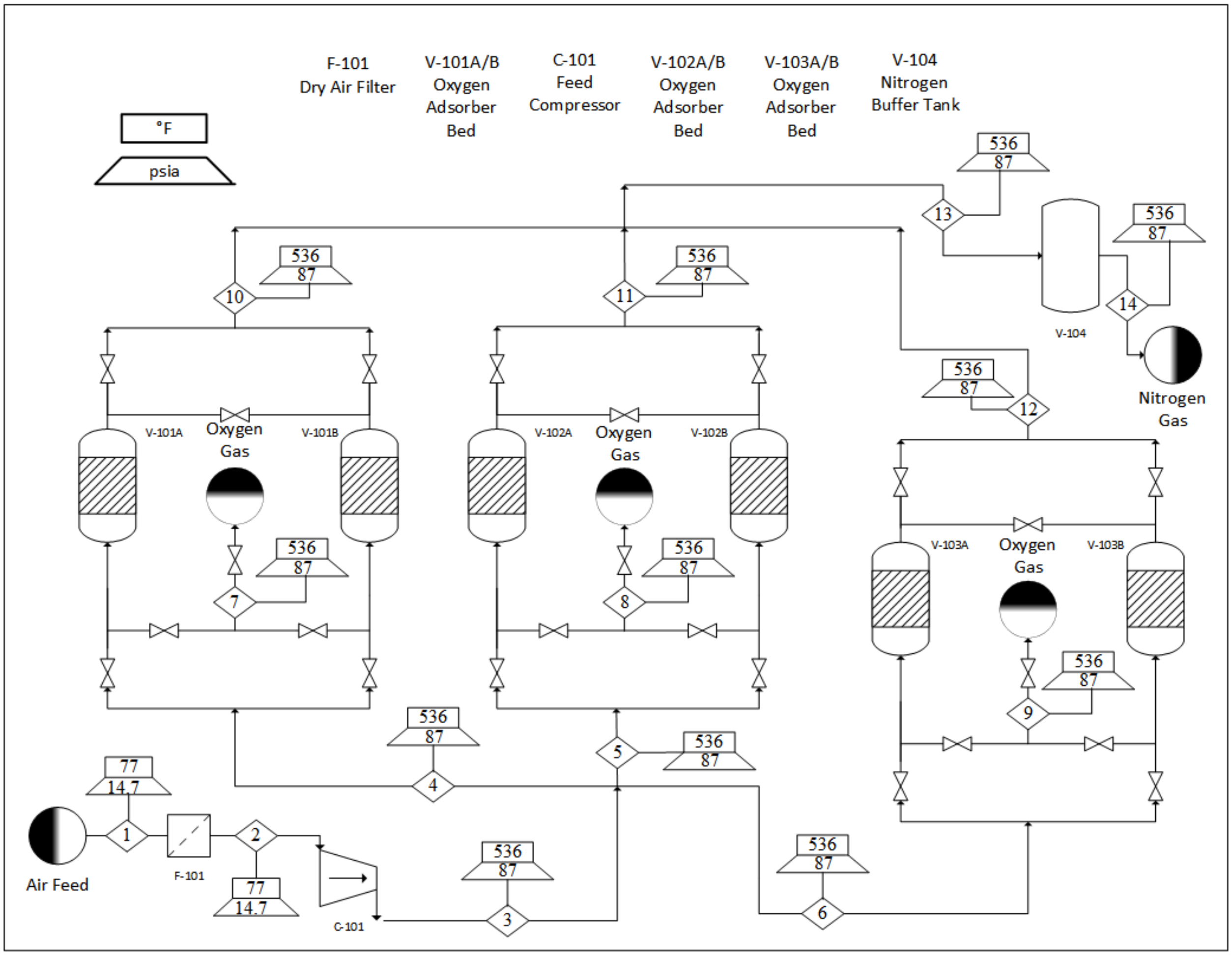

Figure 2: PSA PFD

Table 1: PSA Material Balance

Components	Inlet molar composition	Inlet molar flow rate (mol/s)	Outlet molar composition	Outlet molar flow rate (mol/s)
H2O	0.0007	430.5	0	0
N2	0.781	480257	0.999	480257
O2	0.209	128520	0.995	128520

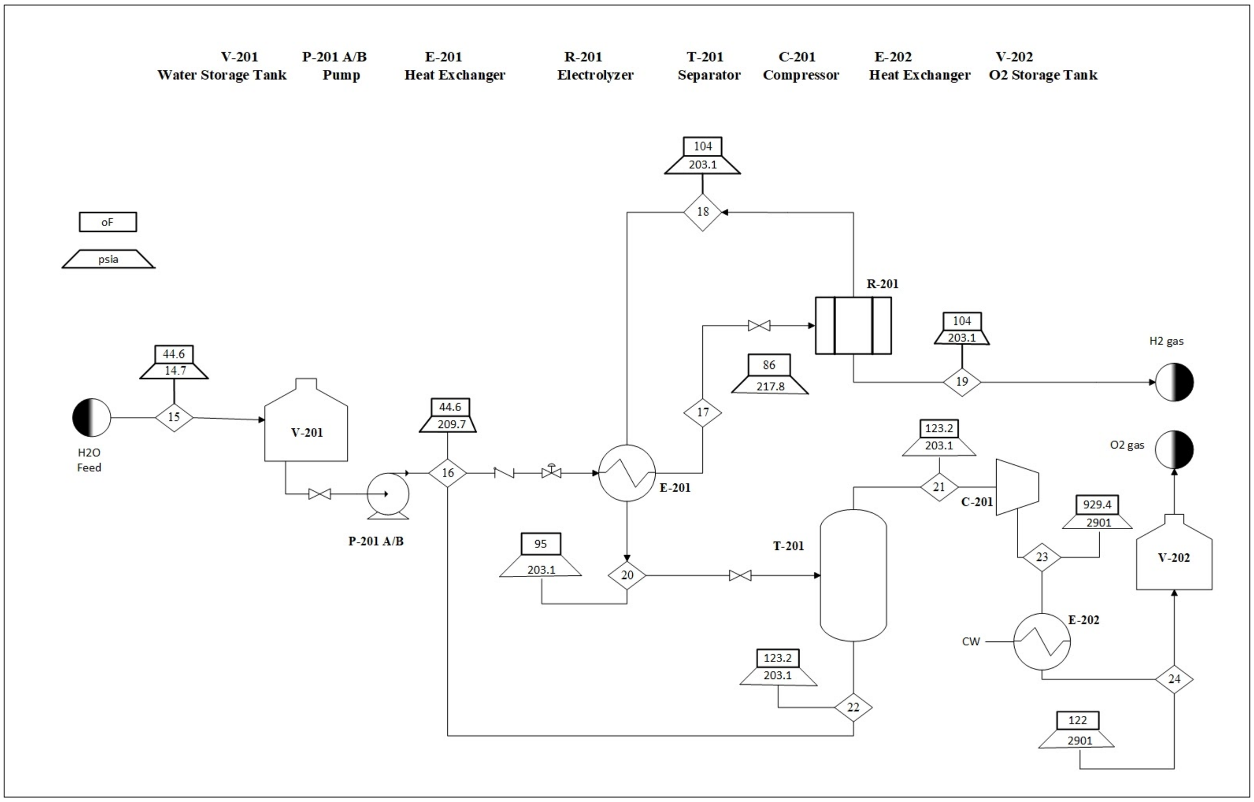

Figure 3: Alkaline Electrolyzer PFD

Table 2: Electrolyzer Material Balance

Components	Inlet molar composition	Inlet molar flow rate (mol/s)	Outlet molar composition	Outlet molar flow rate (mol/s)
H2O	1	51	0	0
H2	0	0	0.99999	51
O2	0	0	0.99	25.5

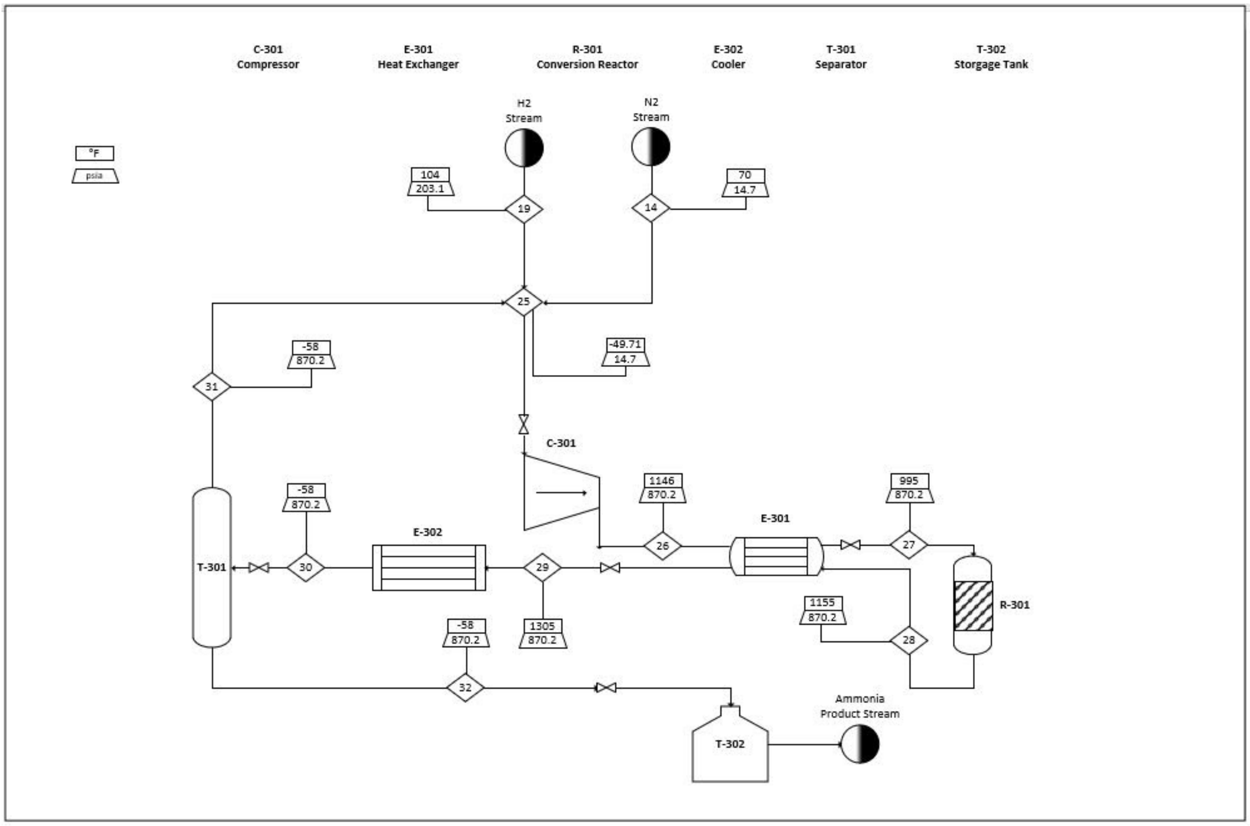

Figure 4: Ammonia Synthesis PFD

Table 3: Ammonia Synthesis Material Balance

Components	Inlet molar composition	Inlet molar flow rate (mol/s)	Outlet molar composition	Outlet molar flow rate (mol/s)
H2	0.999	51	0.002	0
N2	0.999	17	0.000	0
NH3	0.001	0	0.998	34

Process Description

Figure 1 illustrates hydrogen and nitrogen being produced respectively and then entering the ammonia synthesis reactor. The reactant streams are mixed with a recycle stream before going through the Haber-Bosch process to leave as anhydrous ammonia product. In order for the reaction to take place, the reactants must be put through a compressor to meet the high pressures requirements. The gas stream is then heated by both a heat exchanger and conversion reactor. The resulting mixed stream of both unreacted gas and ammonia products must be cooled to the point of phase changing the anhydrous ammonia into liquid for proper storage. After, the stream enters a phase splitter to separate the product from the unused reactants, where the latter makes up the recycle stream. The ammonia product stream is then stored in a pressurized cold storage tank, also shown in the block flow diagram. While the reaction takes place at these conditions, the reaction has equilibrium conditions that allow the newly formed ammonia to revert back into its distinct gas reactants.

Shown in Figure 2, nitrogen gas is produced through the physical separation of the ambient air around the facility. Ambient air is made of roughly 79% N_2 and 21% O_2. The use of a Pressure Swing Adsorber can quickly separate the N_2 into very high purities through the use of compound selective adsorbent, such as Carbon Molecular Sieves. The separated O_2 is also vented back into the atmosphere. The nitrogen production via PSA unit is further discussed on page 8

Figure 3 shows the production of hydrogen gas through electrolysis of water. An electric current is put through water which separates into hydrogen (H_2) and oxygen (O_2) gases. These gases are produced at the anode and cathode specifically, allowing for the separation of the gases at a high purity. Oxygen is compressed and stored into pressurized tanks for storage and sales, while the hydrogen gas is sent downstream to be reacted in the ammonia unit. Electrolysis of water is discussed in greater detail on page 12.

Pressure Swing Adsorption

One of the two reactants required for the ammonia synthesis is nitrogen gas. This reactant is taken from the ambient air available outside the plant. Ambient air, on average, is made of about 78% nitrogen gas. Using a pressure swing adsorber, the nitrogen gas can be separated from the air, to a very pure concentration. There are other methods to separate nitrogen gas from air, including cryogenic air distillation or membrane separators. For ammonia synthesis, it is very important to have minimal impurities. Impurities such as water cause undesired side reactions and interfere with the required production yield. The pressure swing adsorber (PSA) is able to meet the purity demand necessary for the ammonia production, while also having a low cost and power requirement. Since cryogenic air distillation is costly, and membrane generators are not able to reach the purity needed, the PSA unit was the only applicable choice for nitrogen production.

The PSA is made of only a few pieces of equipment, and several valves. Water removal is critical to the process, as water contamination will form undesirable products. Ambient air is made of an average composition of nitrogen gas, oxygen gas, argon, water, and a small percentage of other gases. Argon is negligible in this design since the noble gas is inert. Other trace gases are also negligible due to having significantly smaller compositions.

Following the PSA PFD in Figure 2, stream 1 is the ambient air inlet around the PSA unit. Stream 1 flows through the first piece of equipment, which is the dry air filter F-101. This filter is filled with silica gel desiccant that can last months before being replaced. This filter is also capable of preventing solid particulate from entering the system. After the filter, the dried air in stream 2 is fed to the compressor C-101 which is necessary to drive the separation of the gases in the air[1]. The nitrogen production required is large enough that the feed stream must be split into 3 streams after the compressor to keep the size of the separation beds reasonable. Stream 4, 5, and 6 are identical in size, flow, and composition. Details on each stream can be found in the PSA flow summary table on page 11. The separation beds V-101, V102, and V103 are identical pressure vessels that have been filled with carbon molecular sieve (CMS) material. The packing in the vessels selectively adsorbs the oxygen gas from streams 4, 5, and 6. CMS will strip out the oxygen from the streams and allow the nitrogen to pass further into the process. Eventually the CMS will saturate with oxygen gas and need to be removed. This is the purpose of the second adsorber bed. When a tank in each stream reaches the saturation point, the valves will switch to the regenerated tank in the stream. Only one separating bed is producing nitrogen gas at a time in each stream, while the other separating bed regenerates. The valves are also arranged so that the product nitrogen stream from a separating bed has a small amount routed through the pipe connecting the beds to purge the saturated CMS through streams 7, 8, and 9.

The amount of nitrogen lost while purging oxygen from the CMS packing has been accounted for in the required nitrogen production amount. Because the separating beds are constantly switching between tanks A and B, this PSA is not a continuous process. Each separating bed has an adsorption time, and a desorption time, together they make the cycle time. The separating bed cycle time was heuristically determined to be 240 seconds[2]. The specific adsorption and desorption times were not determined. The separation beds must be staggered so that flow is as close to continuous as possible. This means that to determine the amount of separation tanks needed per stream, heuristics were referenced. The typical number of separation beds in series is 2, while 3 can be utilized if the timings require additional overlap[2].

CMS is a widely used separation material, and this application is common as well, so without special circumstance it was determined that 2 tanks would be used for the preliminary design. After each separation tank, the product streams 10, 11, and 12 are joined together into stream 13 and sent to the buffer tank V-104. This tank serves to convert the nitrogen supply from a “wave” supply, where mass is transferred with peaks and dips as the CMS is saturated and regenerated, to a continuous supply to downstream processing. The buffer tank is sized so that it can handle the throughput of the nitrogen product and allow the tank level to rise and fall with the “waves” of production, but does not empty. This is how “wave” stream 13 converts to continuous stream 14. The waste products of this system are the oxygen vents where separated oxygen is vented back to the atmosphere after being purged from the CMS in streams 7, 8, and 9. The other waste product is the desiccant, as it is replaced monthly when it is fully saturated with water. There is the option to use an air drier very similar to the PSA unit, however the filters were determined to be cheaper due to the lack of additional equipment.

Detailed in the material balance, Table 1, the PSA unit is capable of separating the nitrogen gas from the ambient air. Nitrogen composition is supplied at 78% and processed to 99.9% purity for ammonia synthesis. Water makes up a very small portion of the air, however, due to seasons and locations this can change with humidity. The composition of water in the atmosphere was determined by summing the average composition of nitrogen, oxygen and argon, where the remainder is the available composition for all "other" gases that make up the atmosphere. The project was only focused on the nitrogen, oxygen and water in the air. Argon is negligible due to being inert, but used to find the available composition of water. Table 1, the PSA material balance, and Table 4, the PSA flow summary table, will show that water will enter but not exit the system. This is because the water is being accumulated in the dry air filter at the compressor intake. This design was intentional because of how critical it is to prevent water from entering the process.

Following the PSA Flow Summary, Table 4, each stream was determined based on what the ammonia synthesis unit required to operate. Knowing the required ammonia production and using chemical stoichiometry, the required nitrogen gas could be determined. Using the average composition of nitrogen gas in the air, the required feed flow of dry atmospheric air was determined. The required nitrogen product flow would be the basis of the PSA unit. Working backwards, the PSA must produce 3777 lb/h nitrogen gas. Also accounting for the conditions that no water enters the system, the dry air feed flow would be calculated at 4946 lb/h, from air composition[3]. Knowing the flowrate of dry air and its composition, and having found the available composition of wet air, the wet air flow rate was calculated.

Table 4 : PSA Flow Summary

Stream number:		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Description		Wet Inlet Air Feed	Dried Air Feed	Compressed Dry Air	Split compressed Air	Split Compressed Air	Split Compressed Air	O_2 Waste Vent	O_2 Waste Vent	O_2 Waste Vent	Purified N_2	Purified N_2	Purified N_2	Total N_2 Product	Buffered Nitrogen Product
Temperature (°F)		77	77	536	536	536	536	536	536	536	536	536	536	536	536
Pressure (psia)		14.7	14.7	87	87	87	87	87	87	87	87	87	87	87	87
Vapor fraction		1	1	1	1	1	1	1	1	1	1	1	1	1	1
Enthalpy (Btu/lbmol)		3640.0	6960.2	6960.2	6960.2	6960.2	6960.2	7064.8	7064.8	7064.8	6944.8	6944.8	6944.8	6944.8	6944.8
Mass Flow Rate (lb/hr)	H20	2.16	0	0	0	0	0	0	0	0	0	0	0	0	0
	O2	1146	1146	1146	382	382	382	380.5	380.5	380.5	1.44	1.44	1.44	4.32	4.32
	N2	3779	3,779	3,779	1,260	1,260	1,260	1.67	1.67	1.67	1258	1258	1258	3774	3774
	Total	4927	4925	4925	1641	1641	1641	382.2	382.2	382.2	1259	1259	1259	3779	3779
Total molar flow rate (lbmol/hr)		170.82	170.7	170.7	56.9	56.9	56.9	11.93	11.93	11.93	44.97	44.97	44.97	134.91	134.91
Volumetric Flow rate (Barrel/Day)		292435	292435	89008	29670	29670	29670	6223	6223	6223	23446	23446	23446	70338	70338

Electrolysis of Water

Hydrogen is the second component required for the Haber-Bosch ammonia synthesis process. Hydrogen and ammonia have a 3:2 molar ratio, which means 3 moles of hydrogen are needed to produce 2 moles of ammonia. A high purity hydrogen gas is required to achieve the specified ammonia product purity of 99.5% provided in the design statement.

During the initial phase of this project, the group considered several methods, such as steam method reforming (SMR) using natural gas and electrolysis of water, to produce a high-purity hydrogen. After conducting extensive literature research regarding both methods, electrolysis was the chosen method.

There are various reasons why electrolysis of water was chosen over SMR. The most important reason being to reduce the carbon footprint of the new plant and design it with an innovative approach contrary to the majority of the existing ammonia plants. The SMR utilizes natural gas as a feedstock, which produces carbon dioxide (CO_2) as a byproduct and contributes to global pollution. The existing ammonia production facilities using the SMR method are responsible for 1% of global carbon emission.[4]

Another important deciding factor was to eliminate the need for downstream separation of H_2, which is necessary in SMR method. Electrolysis uses electricity to split water into H_2 and O_2 ; H_2 is produced in the cathode and O_2 is produced in the anode, as shown in Figure 5. As a result, H_2 can be collected from the cathode and sent to the ammonia unit directly, which eliminates the need for downstream separation.

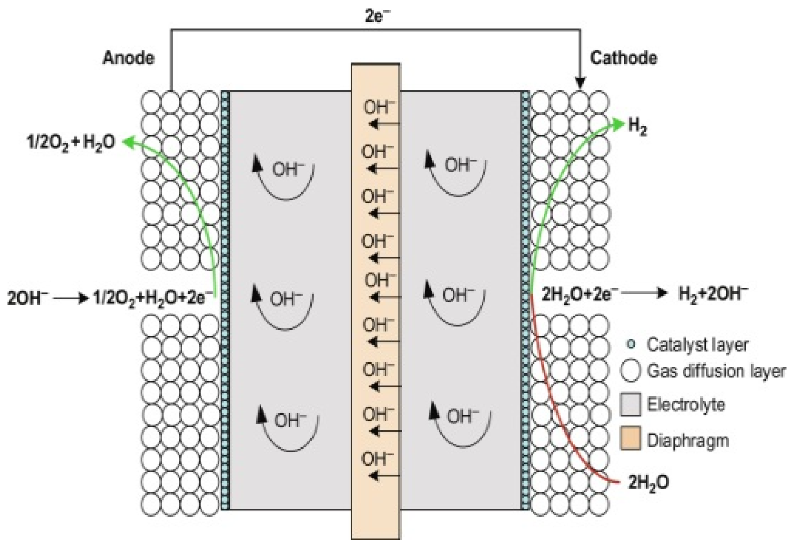

Figure 5: Alkaline Electrolyzer[5]

The figure above shows electrolysis of water in an alkaline electrolyzer. The electrolyzer has two electrodes submerged in the electrolyte, separated by the diaphragm. At the cathode, the water is being split into H_2 and OH^-, where the H_2 is being collected. The OH^- travels through the diaphragm to the anode, where it is further separated into O_2. The electrochemical half reactions along with their cell potentials are shown below.[6] The ΔE^o is the minimum cell voltage required to split water, which is also called the thermoneutral voltage, V_{tn}.

Anode

$$2OH^- \rightarrow \frac{1}{2} O_2 + H_2O + 2e^- \qquad E^o = 0.4 \text{ V}$$

Cathode

$$2H_2O + 2e^- \rightarrow 2H_2 + 2OH^- \qquad E^o = -0.83 \text{ V}$$

Overall

$$H_2O \rightarrow \frac{1}{2} O_2 + H_2 \qquad \Delta E^o = -1.23 \text{ V}$$

The electrolyzer is inherently modular as individual cells can be placed in parallel to make stacks, which make the electrolysis of water more desirable for the project. Furthermore, the electricity used for the electrolyzer is from renewable resources, there are various wind turbine farms and nuclear generating plants present in Minnesota, which makes the H_2 produced carbon free. Another advantage of electrolysis of water is the production of O_2 byproduct, which can be further purified in order to produce industrial gas.

Once the decision to use electrolysis of water for the upstream process to produce ultra-pure H_2 was made, the challenge was to choose the suitable electrolyzer out of the various options available. There are several types of electrolyzers: alkaline electrolyzer, proton exchange electrolyzer (PEM), and solid-oxide electrolyzer cell (SOEC). Upon deliberate consideration and research, the alkaline electrolyzer was determined to be the suitable electrolyzer for our process because of its high durability compared to other types of electrolyzers. Alkaline electrolyzers can also be fabricated with cheaper materials. It also operates with lower temperatures and pressures, which make it inherently safer.[5]

The material balance for the electrolyzer was completed by using Polymath software. A 100% conversion of water into hydrogen and oxygen was assumed to model the material balance. Furthermore, the final H_2 product was calculated based on the material balance for the downstream process to produce ammonia, which was also completed by using Polymath. The hydrogen flow rate required to produce 50 mtpd of anhydrous ammonia was used to determine the initial amount of water needed. Based on the stoichiometry, a 1:1 molar ratio between the reactant H_2O and the product H_2, means that 1 mole of water produces 1 mole of hydrogen. The Table 2 summarizes the material balance for the alkaline electrolyzer. The Polymath report for the electrolyzer is provided on page 131

The process flow diagram (PFD) for the alkaline electrolyzer is shown in Figure 3. Minnesota's soft tap water is used for the source water to the electrolyzer. The electrolyzer has an inbuilt filter that separates the minerals and impurities from the water to avoid degradation of electrodes.

The water storage tank, V-201, will always have water reserved that is necessary for the electrolyzer. The pump, P-201 A/B, will transfer water from the reservoir tank to the heat exchanger, E-201, and eventually to the electrolyzer stacks, R-201. The E-201 is used to heat up the inlet water to a temperature of 86°F by using the electrolyzer outlet process fluids comprised of unreacted H_2O and O_2. It is important to supply the inlet water to the electrolyzer with a temperature as close as the operating temperature in order to avoid electrode overvoltages and degradation.

The R-201 operates at 104°F and 203.1 psia to split the water into hydrogen and oxygen. The produced H_2 leaves the electrolyzer cathode and travels downstream to the ammonia process unit where it is compressed and sent to the ammonia reactor. Further details are provided in the ammonia synthesis PFD, Figure 4. The O_2 produced in the anode and the unreacted H_2O leaves the electrolyzer and enters the tube side of E-201 to heat up the shell side water to a higher temperature, as required by R-201.

The E-201 outlet stream 20 which contains H_2O and O_2 travel further downstream to the separator, T-201, where the two-phase separator produces 99% pure O_2 as a byproduct, and water which is recycled back to stream 16.

The O_2 byproduct leaves the separator and enters the compressor, C-201, where it is being compressed to 2901 psia to meet the storage requirement and sent to the cooler, E-202, and cooled down to 122°F, as required by the standard storage condition. The O_2 byproduct leaves the cooler at 122°F and enters the tank, V-202, where it will be stored.

Feed stream 15 containing 7303 lbm/hr of soft tap water enters the storage tank, V-101, at 44.6°F and 14.7 psia. Water leaves the tank at the same flow rate, pressure and temperature, however, the pump used to transfer the water has a pressure gain of 195 psi, as a result stream 16, entering E-201 has a pressure of 209.7 psia.

The E-201 shell side outlet stream 17, which is also the inlet stream to the electrolyzer, has a pressure of 217.8 psia and a temperature of 86°F. The water enters R-201 at a flow rate of 7309 lbm/hr, it is higher than the storage tank outlet flow rate due to the recycle stream 22 being connected to stream 16. Further details will be provided during the discussion of stream 22 below.

The electrolyzer outlet stream, 18, enters the tube side of E-201 at 104°F and 203.1 psia with 6493 lbm/hr flow rate. The hot process materials enter the tube side because it is a 2-phase mixer, not a pure component like water, putting it in the tube side makes it easier to control. Stream 20, containing the hot process fluid, leaves the heat exchanger and enters T-201 with the same flow rate at 95°F and 203.1 psia.

Stream 19 is the electrolyzer H_2 product stream, which has a flow rate of 816 lbm/hr. The hydrogen leaves the electrolyzer at 104°F and 203.1 psia and travels downstream to the ammonia unit.

The O_2-H_2O separator has two outlet streams, 21 and 22. Stream 21 is the O_2 byproduct stream which has a flow rate of 6487 lbm/hr and enters the compressor at 123.2°F and 203.1 psia. The other outlet stream, 22, from the separator is the water recycle stream, which connects with stream 16 at 123.2°F and 203.1 psia with a flow rate of 6 lbm/hr. Stream 16 has a water flow rate of 7703 lbm/hr, together with the recycled water, there is a total flow rate of 7709 lbm/hr to the electrolyzer stacks.

Stream 23 is the compressor outlet stream and the E-202 inlet stream. O_2 enters the heat exchanger at 929.4°F and 2901 psia. The compressor has a pressure gain of 2698 psi. The oxygen gas is cooled to 122°F and sent to the storage tank at 2901 psia; stream 24 has a flow rate of 6487 lbm/hr. Table 5 has more detailed information about the electrolyzer streams.

Table 5: Electrolyzer Flow Summary

Stream number:		15	16	17	18	19	20	21	22	23	24
Description		Feed to V-201	To shell side of E-201	To Electrolyzer R-201	To tube side of E-201	H_2 outlet stream	To O_2/H_2O separator (T-201)	To O_2 compressor (C-201)	H_2O recycle	To E-202	O_2 (g) Stream
Temperature (°F)		44.6	44.6	86	104	104	95	123.2	123.2	929.4	122
Pressure (psia)		14.7	209.7	217.8	203.1	203.1	203.1	203.1	203.1	2901	2901
Vapor fraction		0	0	0	.9929	1	.9929	1	0	1	.9922
Enthalpy (Btu/lbmol)		3996.16	3996.12	4327.83	3918.82	722.52	-1257	-766.4	-1.22×10^5	5358	-1428
Mass Flow Rate (lb/hr)	H2O	7303	7308	7308	42	0	42	37	5	37	37
	O2	0	1	1	6451	0	6451	6450	1	6450	6450
	H2	0	0	0	0	816	0	0	0	0	0
	Total	7303	7309	7309	6493	816	6493	6487	6	6487	6487
Total Molar Flow Rate (lbmol/hr)		405.7	406	406	203.9	404.7	203.9	203.6	0.3095	203.6	203.6
Volumetric Flow rate (Barrel/Day)		505.6	506	506	391.1	818.7	391.1	390.7	0.3825	390.7	390.7

Ammonia Synthesis

After both the nitrogen and hydrogen have been produced, these reactants go through a conversion reaction to form anhydrous ammonia. The reaction these components go through is named the Haber-Bosch process, and to achieve notable conversion rates the reaction has to occur under high pressure and temperature. Even so, a recycle stream was incorporated into the design to assure that none of the reactants went to waste.

The design packet did offer multiple alternatives that could be researched for their feasibility in regard to ammonia production. One of the processes involved tested multiple catalysts that would lower the temperature and pressure requirements to complete the goal.[7] This alternative did seem promising, but did not look to have the scalability that the more established Haber-Bosch process provided.

In Table 6, it is shown that through the continuous process, almost the entirety of the reactants are reacted, and there is no waste. It is important that both hydrogen and nitrogen come in as nearly pure streams, as the Haber-Bosch process takes place under a very high heat, high pressure environment, and this could be dangerous and wasteful with the additional contaminants.

The PFD shown in Figure 4 illustrates the final major component of the process. Hydrogen and nitrogen vapor streams combine and enter into a compressor to reach 870.2 psia, this is necessary for the following steps in the reaction. This new mixed stream then enters into the tube side of a heat exchanger which heats up due to the shell side reacted product mix stream. This heat integration helps mitigate power consumption as the stream going into the reactor benefits from the higher temperature, and the reacted product stream needs to be chilled for storage. The conversion reaction takes place within the reactor at 1155ºF, shown in the reaction below

Haber-Bosch Reaction

$$N_2 + 3H_2 \rightarrow 2\,NH_3 \qquad H = -87.6 \text{ Btu/lbmol}$$

This process does not fully convert all hydrogen and nitrogen, so the newly reacted stream goes back through the shell side of the heat exchanger. Due to the high heat both the heat exchanger and the conversion reactor must endure, they both have to be made of stainless steel. The stream is still very hot, so it goes through a chiller that lowers the temperature of the stream down to 58ºF using refrigerant R-134a. Once this stream is cooled, it enters into a phase separator, as under these conditions, almost the entirety of the liquid within the stream is ammonia, and the rest of the composition of the stream is gaseous hydrogen and nitrogen, that is sent back into the process via a recycle stream. This liquid anhydrous ammonia is then compressed and put into a storage tank that can hold an excess of up to a day's worth of extra product.

Table 6: Ammonia Synthesis Flow Summary

Stream number		14	19	25	26	27	28	29	30	31	32
Description		Buffered Nitrogen Product	H2 outlet stream	To Compressor	To Heat Exchanger tube	To conversion reactor	To Heat Exchanger shell	To Cooler	To separator	Recycle Stream to Mixer	Ammonia Product
Temperature (°F)		536	104	-49.71	1146	995	1155	1305	-58	-58	-58
Pressure (psia)		87	203.1	14.7	870.2	870.2	870.2	870.2	870.2	870.2	870.2
Vapor fraction		1	1	1	1	1	1	1	0.947	1	0
Enthalpy (Btu/lbmol)		563.6	722.2	-1040	7444	6338	6671	7835	-2765	-1186	-31189
Mass Flow Rate (lb/hr)	H2	0	816	38222	38222	38222	36161	36161	36161	34412	10
	N2	4195	0	12878	12878	12878	12157	12157	12157	11564	0
	NH3	0	0	464	464	464	3194	3194	3194	464	5062
	Total	4195	816	51512	51512	51512	51512	51512	51512	46440	5072
Total Molar Flow Rate (lbmol/hr)		149.8	446.2	5966	5966	5966	5669	5669	5669	5370	298.2
Volumetric Flow Rate (Barrel/Day)		242,300	722,600	9,661,000	9,661,000	9,661,000	9,178,000	9,178,000	9,178,000	869,6000	568.8

Energy Balance and Utility Requirements

Table 7 shows the required utilities to run the process. Water is required for use in the electrolyzer. Electricity is used by the compressors, chiller, electrolyzer, pumps, and reactor to operate properly. Details on the power consumption of the equipment requiring electricity are outlined in the next table, Table 8.

Table 7: Required Utilities

Utility	Price	Unit
Water	1.94	$/1000 gallons
Electricity	0.0654	$/kW
Silica Gel	100	$/55 lb bag

Shown in Table 8 are the utility requirements of the process. The most power consumption occurs at C-301, R-201, and E-302. C-301 is the ammonia feed compressor that has to achieve a high pressure to push the reaction to occur, this compressor and the power it consumes are critical for the process. E-302 is the ammonia chiller and is required to achieve the phase change in the ammonia in order to put it into cold storage tanks. Heat exchanger E-302 is critical to the process to produce the ammonia in a form that can be transported. R-201 is the electrolyzer producing the hydrogen gas reactant. This equipment is a green alternative to hydrogen production and provides both the hydrogen gas reactant, and the byproduct oxygen gas that is contributing to the revenue of the project.

Table 8: Utility Consumption

Equipment	Consumption	Unit
P-201 A/B	66.02	kW/hr
C-101	5.24	kW/hr
C-201	365.4	kW/hr
C-301	10.48	MW/hr
R-201	1.46	MW/hr
T-201	18.3	kW/hr
E-202	405	kW/hr
E-302	11.29	MW/hr

The product ammonia and oxygen gas are the sources of revenue in this project. Ammonia is able to be sold for an estimated price of $503.62/ton. This is a somewhat conservative sale price and is sourced from utility providers in the Nebraska, Minnesota, and Illinois state areas. Similarly with oxygen gas, this is medical-grade purity and can be sold for $40/ton. These are the only sources of revenue in the process, with variable sales price depending on the specific location of the plant. Initially the plant is expected to use electricity sourced from coal driven power plants, with the expectation that the industrial need brought by this plant will encourage wind power to be developed in the minnesota region. The wind power will further lessen the carbon footprint of the plant.

Table 9: Component Prices

Component	Purchase/Sale Location	Price (2019)	Unit
Anhydrous Ammonia	Nebraska, Minnesota, Illinois	$503.62	$/ton
O2 gas	Minnesota	$40	$/ton

Equipment List and Unit Descriptions

For the PSA equipment only 4 distinct pieces of equipment had to be designed. The dry air filter, compressor, 6 identical separation beds, and nitrogen buffer tank. The overall equipment needed is 9 pieces of equipment. The filter internals have to be exchanged each month, and the separation beds have to be replaced every 10 years.

Table 10: PSA Equipment List

Equipment	Name	Quantity
F-101	Dry Air Filter	1
C-101	Air Feed Compressor	1
V-101A/B	Pressure Swing Adsorber Bed	2
V-102A/B	Pressure Swing Adsorber Bed	2
V-103A/B	Pressure Swing Adsorber Bed	2
V-104	Nitrogen Buffer Tank	1

The PSA equipment summary is provided in Table 11 The summary provided in the table includes the parameters that adequately size the equipment for the process requirements. Each piece of equipment follows safety heuristics to account for pressure and temperature safety factors used in standard engineering practices. The pressure was increased by 50 psi to the operating pressure shown in the equipment description lists on Table 12. Temperature was increased for safety. Due to the proximity of the temperature to the critical failure temperature of carbon steel, all of the equipment must be made of stainless steel to account for fluctuations that may occur during operation.

Table 11: PSA PFD Equipment Summary

COMPRESSORS	**C-101**			
Flow (lb/hr)	4946			
Fluid Density (lb/ft3)	0.236			
Power (shaft) (hp)	7.02			
MOC	Stainless Steel			
Filter	**F-101**			
Size (CFM)	30			
Amount (oz)	155			
Internals	Silica Gel			
Vessels	**V-101 A/B**	**V-102 A/B**	**V-103 A/B**	**V-104**
Temp(°F)	600	600	600	600
Pressure (psia)	140	140	140	140
Orientation	Vertical	Vertical	Vertical	Vertical
MOC	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel
Size	**V-101 A/B**	**V-102 A/B**	**V-103 A/B**	**V-104**
Height/Length (ft)	10.7	10.7	10.7	34.1
Diameter (ft)	3.58	3.58	3.58	11.35
Internals	CMS	CMS	CMS	-

Table 12 shows the designed operating parameters for the PSA equipment. The compressor was sized through Aspen HYSYS for compressing the incoming dry air stream from atmospheric pressure to 87 psia. Due to the operating temperature being so close to the mechanical failure temperature, the compressor must be made out of stainless steel. Aspen HYSYS was able to provide the power required to run as well as the stream temperature at the outlet of the compressor.

The air filter was sized by taking the flowrate of the air into the PSA system, and converting the flowrate's units to CFM and finding the most appropriately sized filter to buy. The desiccant air dryer was the best suited demoisturizing filter for the type of process at hand.

Each separation bed was found using design equations listed in Appendix V on page 112[2][11]. The required nitrogen production was known, as well as the composition of the atmospheric air. Using component densities at respective pressure and temperature[3], adsorption capacity of the CMS internals[13] and the bulk density of the internals[12], the overall required amount of CMS could be determined. Using engineering heuristics to size a pressure vessel with an L/D ratio of either 3 or 4.5, the tanks could be sized with respect to how many times the compressed feed stream was split.

The buffer tank following the outlet of the PSA was sized using equations in the aforementioned Appendix V on page 116[14]. The buffer tank sizing relied heavily on the appropriate buffer volume necessary for the inlet and outlet flow rates. To get an appropriate volume, an equation relating the volume of a half full tank to its outlet flow rate and residence time was used. While the outlet flow rate for this tank was a known value specific to the process, the residence time followed an industry standard residence time of 7 minutes[14]. This was specified for tanks undergoing this general function within the process. Following this equation led to finding an appropriate tank volume, which was then increased by an additional 10% standard oversizing factor[14]. After concluding to a specific overall buffer tank volume, the base dimensions of the tank were modeled following the same equations utilized in the PSA sizing. The same L/D ratios, 3.0 and 4.5, used in sizing the PSA tanks were also appropriate in sizing the buffer tank. From these ratios the height and diameter of the tank could be calculated assuming the shape of the tank was that of a standard cylinder with hemispheres attached to its top and bottom.

Table 12: PSA PFD Equipment Description

Equipment
Description of Equipment
Compressor (C-101)
C-101 $\dot{m}$: 4946 lb/hr, ΔP: 72.3 psia, T:536°F, P: 7.02 hp MOC: Stainless Steel
Air Filter (F-101)
Size: 30 CFM, Internals: silica gel, Internals lifespan: 2 years
Pressure Swing Adsorber Beds (V-101 A/B, V-102 A/B, V-103 A/B)
V-101 A/B D: 3.58 ft, h: 10.7 ft, P: 87 psia, T: 536°F MOC: Stainless Steel Orientation: Vertical **V-102 A/B** D: 3.58 ft, h: 10.7 ft, P: 87 psia, T: 536°F MOC: Stainless Steel Orientation: Vertical **V-103 A/B** D: 3.58 ft, h: 10.7 ft, P: 87 psia, T: 536°F MOC: Stainless Steel Orientation: Vertical
Nitrogen Buffer Tank (V-104)
V-104 D: 11.35 ft, h: 34.1 ft, P: 87 psia, T: 536°F MOC: Stainless Steel Orientation: Vertical

The parallel modular electrolyzer unit consists of compressor, heat exchangers, alkaline electrolyzer, separator, and storage vessels. The alkaline electrolyzer is the most important piece of equipment in this unit. The Table 13 provides the complete equipment list for the electrolyzer unit.

Table 13: Electrolyzer Equipment List

Equipment	Name	Quantity
R-201	Alkaline Electrolyzer	125 stacks
T-201	O2-H2O separator	1
V-201	H2O Storage	1
V-202	O2 Storage	1
E-201	Heat Exchanger	1
E-202	Heat Exchanger	1
P-201 A/B	Electrolyzer feed pump	2
C-202	O2 compressor	1

Table 14 below summarizes the equipment design and sizing parameters. All of the equipment was designed based on the operation conditions from the PFD shown in page 5. However, each equipment was designed to account for pressure and temperature safety factors according to engineering safety standards. The pressure safety factor was accounted for by either adding an additional 10% of the operation pressure or 50 psi, whichever one was greater.

Even though there aren't any specific safety factor guidelines for temperature, the operating temperature was doubled in certain instances, while it was quadrupled for other equipment based on the material and process the equipment is responsible for. The upper temperature limit was constrained by the material of construction (MOC) used for each type of equipment. The pressure and temperature constraints of different types of materials presented in the Turton textbook was used to further verify the design temperature for each equipment[11].

Table 14: Electrolyzer PFD Equipment Summary

REACTOR	**R-201**		
Temp(°F)	450		
Pressure (psia)	267		
Orientation	Vertical		
MOC	Carbon Steel		
Size	**R-201**		
Area (ft^2)	5.4		
Cell	20		
Stack	125		
Electrolyte	KOH		
MOC	Carbon Steel		
Vessels/ Towers	**T-201**	**V-201**	**V-202**
Temp(°F)	450	400	400
Pressure (psia)	267	64.7	3192
Orientation	Vertical	Vertical	Horizontal
MOC	Carbon Steel	Carbon Steel	Carbon Steel
Size	**T-201**	**V-201**	**V-202**
Height/Length (ft)	10	5.25	4
Diameter (ft)	5	1.75	2
MOC	Carbon Steel	Carbon Steel	Carbon Steel
Heat Exchangers	**E-201**		**E-202**
Type	AFS		AXS
Area (ft^2)	66		50
Duty (Btu/hr)	3.02×10^5		1.381×10^6
Shell	**E-201**		**E-202**
Temp(°F)	450		1112
Pressure(psia)	283		3192
Phase	Liquid		Gas
MOC	Carbon Steel		Stainless Steel
Tube	**E-201**		**E-202**
Temp(°F)	450		450
Pressure(psia)	283		283
Phase	Liquid-Vapor		Liquid
MOC	Copper		Stainless Steel
Pumps	**P-201 A/B**		

Flow (gpm)	575
Fluid Density (lb/ft3)	62.4
Power (shaft) (hp)	92
MOC	Carbon Steel
COMPRESSORS	**C-201**
Flow (lb/hr)	6487
Fluid Density (lb/ft3)	1.044
Power (shaft) (hp)	490
MOC	Stainless Steel

The alkaline electrolyzer was designed according to a mathematical model by using Matlab to produce high-purity hydrogen gas.[12][13] In order to produce 816 lbm/hr of hydrogen with a 99.999% purity, 125 electrolyzer stacks made of 20 cells each are needed. The cells are placed in parallel to make an individual stack. The electrodes within the cell were designed to have an area of 5.4 ft^2. The electrolyzer was designed to operate at 104°F and 203.1 psia with a 50% efficiency. Furthermore, the electrolyzer requires 4.98 x 10^6 Btu/hr to produce H_2. Potassium hydroxide (KOH) was chosen to be the electrolyte. The electrolyzer design equations and Matlab codes are provided in Appendix 3 in page 95

The oxygen-water mixture is sent to the downstream separator, T-201, to produce 99% pure O_2 gas byproduct. The separator was designed in HYSYS to produce oxygen at the required purity. A L/D ratio of 2 was assumed to size the equipment in HYSYS. The separator operates at 123.2°F and 203.1 psia and processes 6493 lbm/hr of oxygen-water mixture fluid. Detailed design information is provided in the HYSYS report on page 130.

There are two storage vessels, V-201 and V-202, in the electrolyzer unit. V-201 stores the water for the electrolyzer at atmospheric pressure, while V-202 stores pressurized O_2 gas. The two storage vessels were designed with a similar approach. For V-201, we assumed a L/D factor of 3 and for V-202 a L/D factor of 2. The volume of the tanks were determined based on the flow rates of water and oxygen to the corresponding tank. The storage vessel, V-201 has a volume of 201 ft^3 and V-202 has a volume of 258 ft^3. The listed volume has an additional 10%

safety factor. The water in V-201 is stored at 14.7 psia and 44.6°F, and the O_2 gas in V-202 is stored at 2901 psia and 122°F.

The Tubular Exchanger Manufacturers Association (TEMA) table provided in the GPSA handbook was used to determine the different heat exchanger types shown in the Table 14 above[15]. We choose an AFS type heat exchanger for E-201 and an AXS type for E-201. The A front end stationary head type has a channel and removable cover, F shell type has two pass shells with longitudinal baffle, X shell type has cross flow, and S rear end head type has floating head with backing device.

The heat exchangers, E-201 and E-202, were designed following engineering standards. The heat duty, Q, for E-201 was estimated to be 3.02×10^5 Btu/hr by using Equation 1, for the hot process fluid. The heat duty for E-201 was calculated to be 1.381×10^6 Btu/hr from the HYSYS simulation for O_2-H_2O separation.

$$\boxed{Q = (m\ cp\ \Delta T)_h = (m\ cp\ \Delta T)_c} \qquad 1$$

In order to find the area of each heat exchanger, we used the energy balance equation. Equation 2, shown below, has two other parameters, U and LMTD, other than Q, that needs to be calculated before we can estimate the area.

$$\boxed{Q = UA\Delta T lm} \qquad 2$$

The energy balance equation uses the logarithmic mean temperature difference (LMTD) to estimate the surface area necessary for heat transfer. The LMTD was determined by using Equation 3

$$LMTD_{countercurrent} = \frac{(T_{h,i}-T_{c,o})-(T_{h,o}-T_{c,i})}{\ln\left(\frac{T_{h,i}-T_{c,o}}{T_{h,o}-T_{c,i}}\right)} \qquad 3$$

Once the LMTD was determined, we applied the correction factor, F, to find the corrected mean temperature difference (CMTD), as shown in Equation 4. The graph used to find the F is provided on page 89 in Appendix 1.

$$MTD = F \cdot LMTD_{countercurrent} \qquad 4$$

The overall heat transfer coefficient, U, is another important parameter in the energy balance equation. Based on the convection heat transfer coefficients, h_i and $h_{o,}$ in the inner and outer wall, and the fouling factors, R_{fi} and R_{fo}, Equation 5 was used to estimate U. E-201 was designed to have counter-current flow with the cold water in the shell side and the hot process fluid of O_2 and H_2O mixture in the tube side. The h_i and h_o coefficients were chosen with a moderate range approach from the lecture notes posted for the design course[16]. The h_o value of 1145.5 Btu/hr ft^2 °F and h_i value of 264.3 Btu/hr ft^2 °F were chosen for E-201. With the similar approach as E-201, we designed E-202 to have counter-current flow with the hot process fluid in the shell side and the cooling water in the tube side. We choose moderate value of 1145.5 Btu/hr ft^2 °F for h_o and 141 Btu/hr ft^2 °F for h_i. For the fouling resistance, we had an conservative approach and chose smaller R_{fi} and R_{fo} values for both heat exchangers. Once we had all the necessary information, the overall heat transfer coefficient for both heat exchangers was calculated. For E-201, the U was found to be 161.6 Btu/hr ft^2 °F, while E-202 U value was calculated to be 110 Btu/hr.

$$U_o = [\frac{1}{h_i} + R_{fi} + R_{fo} + \frac{1}{h_o}]^{-1} \qquad 5$$

The surface area necessary for each heat exchanger was then determined; E-201 has an area of 66 ft^2 and E-202 has an area of 50 ft^2.

The design and sizing of pump, P-201 A/B, was completed by using GPSA handbook guidelines. The amount of fluid through the pump was calculated to be 14.6 gpm from the Matlab electrolyzer model. However, the pump was designed to have a maximum flow rate of 575 gpm based on the head of 499 ft. Based on the pressure gain across the pump, the calculated head was 453.5 ft, however an additional 10% safety factor was added. We determined ΔP across the pump to be 191 psi by using standard friction values provided in the GPSA handbook[15].The Figure 6 shows the pump sizing curve used to estimate the maximum flow rate for a 10.5 ft diameter pump.

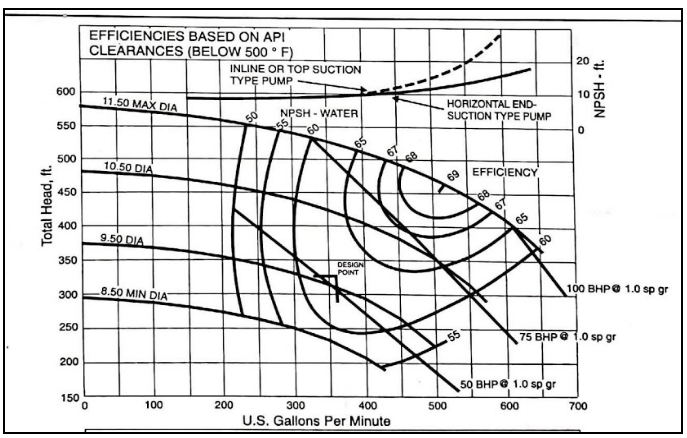

Figure 6: Pump sizing from GPSA handbook[15]

The hydraulic hp for the pump was calculated based on the maximum flow rate of 575 gpm and a ΔP of 191 psi, using Equation 6. Then the calculated hydraulic hp of 65.4 hp was utilized to determine the brake hp, using Equation 7. The pump efficiency required for brake hp was estimated to be 80% by using Figure 7.

$$Hydraulic\ hp = \frac{Q\Delta P}{1715} \qquad (6)$$

$$Brake\ hp = \frac{hydraulic\ hp}{\eta pump} \qquad (7)$$

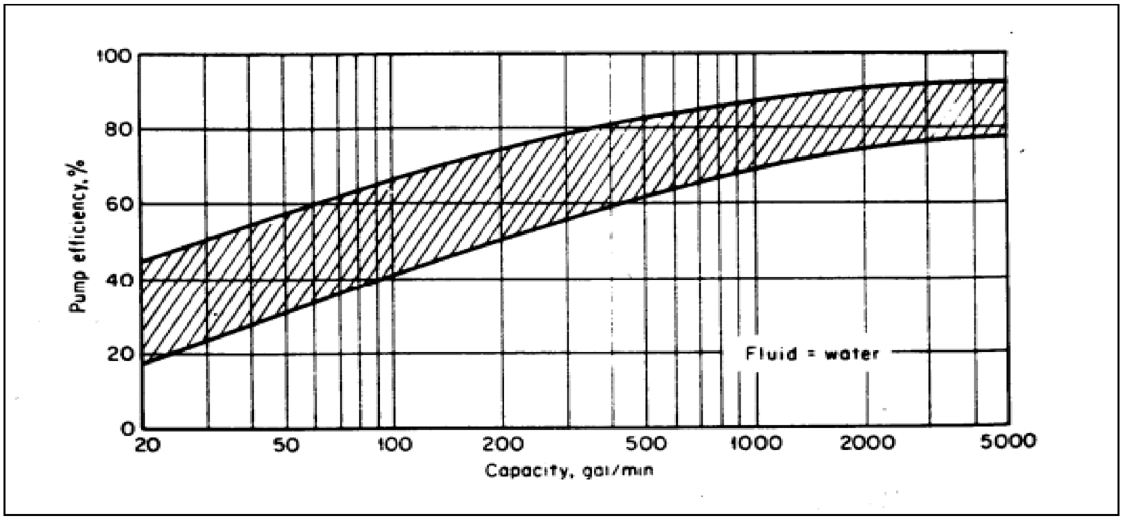

Figure 7: Pump Efficiency[17]

Similar to the brake hp, the purchase hp was calculated by using Equation 8. The motor efficiency was estimated by using the calculated brake hp from Figure 8. The pump, P-201 A/B has a 90% motor efficiency at a brake hp of 81.7 hp. The purchase hp for the pump was calculated to be 91 hp based on Equation 8.

$$Purchased\ hp = \frac{Brake\ hp}{\eta motor} \qquad (8)$$

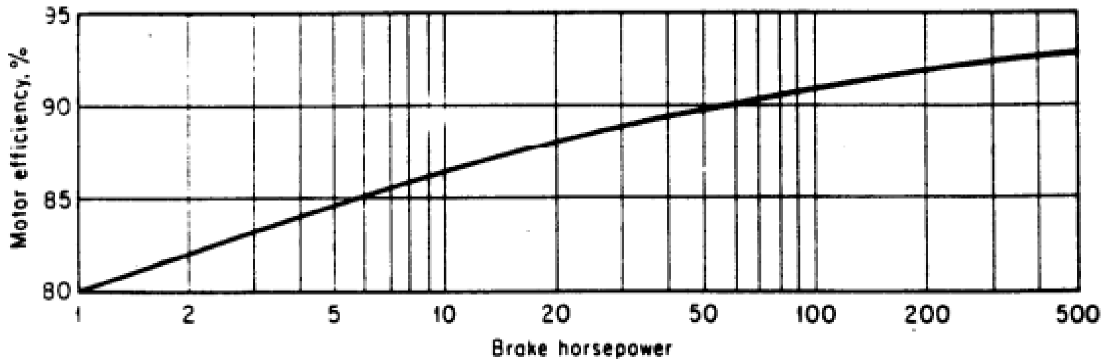

Figure 8: Motor Efficiency[17]

The compressor, C-201, was modeled in HYSYS. It is necessary to compress the O_2 gas to 2901 psia for storage as a result the designed compressor has a ΔP of 2698 psi and a power of 490 hp. The compression is happening in 2 stages with a compression ratio of 3.77. The compressor was sized to handle 6487 lbm/hr of O_2 gas. For more information regarding the sizing of the compressor, HYSYS simulation report is provided on page 130.

The operating conditions for the electrolyzer modular unit is provided below in Table 15. The utility costs were calculated by using the operating conditions from the electrolyzer PFD provided in Figure 3.

Table 15: Electrolyzer PFD Equipment Description

Equipment
Description of Equipment
Electrolyzer (R-201)
P**:** 203.1 psia, T:104°F, 1954.7 hp, Area: 5.4 ft^2 MOC: Carbon Steel
Separator (T-201)
D: 5 ft, L: 10 ft, P: 203.1 psia, T: 123.2°F MOC: Carbon Steel
H2O Storage Tank (V-201)
D: 1.75 ft, L: 5.25 ft, P: 14.7 psia, T: 44.6°F MOC: Carbon Steel
O2 Storage Tank (V-202)
D: 2 ft, L: 4 ft, P: 2901 psia, T: 122°F MOC: Carbon Steel
Heat Exchangers (E-201, E-202)
E-201 Type: AFS Shell: 209.7 psia, 44.6°F; Tube: 203.1 psia, 104°F; Duty: $3.02x10^5$ Btu/hr, Area: 193 ft^2 MOC: CS shell/ Cu tube **E-202** Type: AXS Shell: 2901 psia, 929.4°F; Tube: 209.7 psia, 44.6°F; Duty: $1.381x10^6$ Btu/hr, Area: 50 ft^2 MOC: SS shell/ SS tube
Pumps (P-201 A/B)
P-201 A/B 14.6 gpm,14.7 psia, 44.6°F, ΔP: 195 psi, 91 hp Drive Electric Motor MOC: Carbon Steel
Compressors (C-201)
C-201 390.7 barrel/day, 203.1 psia, 929.4°F, ΔP: 2698 psi, 490 hp MOC: Stainless Steel

The ammonia synthesis requires six major pieces of equipment after the reactants enter in from both the PSA and the alkaline electrolyzer. This process consists of the compressor, conversion reactor, two heat exchangers, phase separator and a storage tank to store the liquid product. The second heat exchanger is a cooler, and refrigerant R-134a is cycled through to continuously cool the ammonia into its liquid phase.

Table 16: Ammonia Synthesis Equipment List

Equipment	Name	Quantity
C-301	Compressor	1
R-301	Conversion Reactor	1
E-301	Heat Exchanger	1
E-302	Cooler	1
T-301	Separator Column	1
V-301	Storage Tank	1

The equipment in Table 17 shows the operating conditions and other specifications that each piece of equipment needs to operate at. The conversion reactor and heat exchange must endure the high temperatures required for the reaction to take place, which made it necessary for them to be stainless steel. All other equipment would be made out of the cheaper carbon steel. Safety heuristics were followed, just as with the other parts of the plant to safely handle each of the pieces of equipment sized within the HYSYS program.

Table 17: Ammonia Synthesis PFD Equipment Summary

REACTOR	**R-301**	
Temp(°F)	1155	
Pressure (psia)	870.2	
Orientation	Vertical	
Size	**R-301**	
Height/Length (ft)	2.12	
Diameter (ft)	13.12	
MOC	Stainless Steel	
Vessels/Towers	**T-301**	**V-301**
Temp(°F)	-58	-58
Pressure (psia)	870.2	870.2
Orientation	Vertical	Vertical
Size	**T-301**	**V-301**
Height/Length (ft)	10	118
Diameter (ft)	5	58.5
Orientation	Vertical	Vertical
MOC	Carbon Steel	Carbon Steel
Heat Exchangers	**E-301**	**E-302**
Type	Floating Head	Cooler
Area (ft^2)	193	480.0
Duty (Btu/hr)	6598000	60080000
Shell	**E-301**	**E-302**
Temp Change (°F)	150.7	N/A
Pressure(psia)	870.2	N/A
Phase	Vapor	N/A
MOC	Stainless Steel	N/A
Tube	**E-301**	**E-302**
Temp Change (°F)	150.6	85.7
Pressure(psia)	870.2	14.7
Phase	Vapor	Liquid
MOC	Stainless Steel	Carbon Steel
COMPRESSORS	**C-301**	

Flow (lb/hr)	51512
Fluid Density (lb/ft3)	2.884
Power (shaft) (hp)	19890
MOC	Stainless Steel

Table 18 shows the specific conditions that the equipment operates at. Every piece of equipment was designed within HYSYS. Once the amount of the reactants necessary to create the 50 tons of anhydrous ammonia was calculated, and later on designed, the operating conditions at which everything within the system were determined. Since the Haber-Bosch process requires high temperature and pressure, the reactor and heat exchange were required to be manufactured out of stainless steel.

The storage tank was sized by taking the HYSY volumetric flow rate out of the phase separator and multiplying it by 24 hours to get the full day's total volume of ammonia. After finding this amount, the amount would be multiplied by an extra 10% for safe practice. To get both the length and diameter, an L/D factor of 2 was used.

Table 18: Ammonia Synthesis PFD Equipment Description

Equipment
Description of Equipment
Ammonia Reactor (R-301)
V: 287.5 ft^3, P: 870.2 psia, T: 1155°F MOC: Stainless Steel
Separator (T-301)
D: 5 ft, L: 10 ft, P: 14.7 psia, T: -49.71°F MOC: Carbon Steel
Storage Tank (V-301)
Vertical D: 58.53 ft , L: 117.1 ft, P: 870.2 psia, T: -58°F MOC: Carbon Steel
Heat Exchangers (E-301, E-302)
E-301 Type: AEL Shell: 870.2 psia, 1146°F; Tube: 870.2 psia, 1155°F; Area: 193 ft^2 MOC: Stainless Steel **E-302** Type: Cooler psia, -58°F; Duty: $6.008x10^7$ Btu/h, Area: 585 ft^2 MOC: Carbon Steel
Compressors (C-301)
C-301 12380 barrel/day, ΔT: 1195°F, ΔP: 855 psi, 19890 hp MOC: Stainless Steel

Equipment Specification Sheets

Compressor			
Identification:	**Item** Item No. No. Required	*Air Feed Compressor* C-101 1	Date: *24 March 2020* By: *AIChE Design Group*
Function:	Compressor Air Intake Feed		
Operation:	Continuous		
Materials Handled:		*Air Feed*	*Compressed Air Feed*
	Quantity (lb/hr)	4946	4946
	Composition:		
	Nitrogen	0.79	0.79
	Oxygen	0.21	0.21
	Temperature (°F)	77	536
Design Data:	Pressure Inlet: 14.7 psi Pressure Outlet: 87 psi Material of Construction: Stainless Steel Power: 7.02 hp Number of Stages: 2 Compression Ratio: 5.92		
Utilities: 5.24 kW of municipal city electricity **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 1, pg# 11			

Figure 9: Compressor (C-101) Specification Sheet

Compressor			
Identification:	**Item** Item No. No. Required	*O2 Compressor* C-201 1	Date: *24 March 2020* By: *AIChE Design Group*
Function:	Compress O2		
Operation:	Continuous		
Materials Handled:		*O2 Feed*	*Compressed O2 gas*
	Quantity (lb/hr)	6487	6487
	Composition:		
	Oxygen (O2)	0.99	0.99
	Water (H2O)	0.01	0.01
	Temperature (°F)	123.2	929.4
Design Data:	Pressure Inlet: 203.1 psia Pressure Outlet: 2901 psia Material of Construction: Stainless Steel Power: 490 hp Number of Stages: 2 Compression Ratio: 3.77		
Utilities: 365.4 kW of municipal city electricity **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 2, pg# 17			

Figure 10: Compressor (C-201) Specification Sheet

Compressor			
Identification:	**Item** Item No. No. Required	*Mixed feed Compressor* C-301 1	Date: *25 March 2020* By: *AIChE Design Group*
Function:	Compressor of Mixed Feed		
Operation:	Continuous		
Materials Handled:		*Mixed Feed*	*Compressed Mixed Feed*
	Quantity (lb/hr)	51512	51512
	Composition:		
	Hydrogen (H2)	0.74	0.74
	Nitrogen (N2)	0.25	0.25
	Ammonia (NH3)	0.01	0.01
	Temperature (°F)	-49.71	1146
Design Data:	Pressure Inlet: 14.7 psi Pressure Outlet: 870.2 psi Material of Construction: Stainless Steel Power: 19894 hp Number of Stages: 2 Compression Ratio: 7.7		
Utilities: 10480 kW of municipal city electricity **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 3, pg# 19			

Figure 11: Compressor (C-301) Specification Sheet

Heat Exchanger				
Identification: **Item** Item No. No. Required	*Heat Exchanger* E-201 1		Date: *24 March 2020* By: *AIChE Design Group*	
Function: Heat transfer between cold H_2O feed and Hot Process				
Operation: Continuous				
Materials Handled:	*H2O Cold Feed in*	*H2O Cold out*	*H2O&O2 inlet*	*H2O&O2 outlet*
Quantity (lb/hr)	*7309*	*7309*	*6493*	*6493*
Composition:				
Water (*H2O*)	*1*	*1*	*0.0115*	*0.0115*
Hydrogen (H2)	*0*	*0*	*0*	*0*
Oxygen (O2)	*0*	*0*	*0.9885*	*0.9885*
Temperature (°F)	*44.6*	*86*	*104*	*95*
Design Data: Type: AFS Shell Pressure: 283 psia Tube Pressure: 283 psia Area: 66 ft^2 MOC: Carbon Steel Shell/ Copper Tube				
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 2, pg# 17				

Figure 12: Heat Exchanger (E-201) Specification Sheet

Heat Exchanger					
Identification:	**Item** Item No. No. Required	*Heat Exchanger* E-202 1		Date: *24 March 2020* By: *AIChE Design Group*	
Function:	Heat transfer between cold H_2O feed and Hot Process				
Operation:	Continuous				
Materials Handled:		*H2O Cold in*	*H2O Cold out*	*O2 gas inlet*	*O2 gas outlet*
Quantity (lb/hr)		*7793*	*7793*	*6487*	*6487*
Composition:					
Water (*H2O*)		*1*	*1*	*0.01*	*0.01*
Oxygen (O2)		*0*	*0*	*0.99*	*0.99*
Temperature (°F)		*44.6*	*125*	*929.4*	*122*
Design Data: Type: AXS Shell Pressure: 3192 psia Tube Pressure: 283 psia Area: 50 ft^2 MOC: Stainless Steel Shell/Stainless Steel Tube					
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 2, pg# 17					

Figure 13: Heat Exchanger (E-202) Specification Sheet

Heat Exchanger					
Identification:	**Item** Item No. No. Required	*Heat Exchanger* E-301 1		Date: *25 March 2020* By: *AIChE Design Group*	
Function:	Heat transfer between mixed feed before and after conversion				
Operation:	Continuous				
Materials Handled:		*Mixed Feed in*	*Mixed Feed out*	*Converted inlet*	*Converted outlet*
	Quantity (lb/hr)	*51512*	*51512*	*51512*	*51512*
	Composition:				
	Hydrogen (H2)	*0.74*	*0.74*	*0.70*	*0.70*
	Nitrogen (N2)	*0.25*	*0.25*	*0.24*	*0.24*
	Ammonia (NH3)	*0.01*	*0.01*	*0.06*	*0.06*
	Temperature (°F)	*1146*	*995*	*1155*	*1305*
Design Data: Type: AEL Shell Pressure: 870.2 psia Tube Pressure: 870.2 psia Area: 193 ft^2 MOC: SS Shell/ SS Tube					
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 3, pg# 19					

Figure 14: Heat Exchanger (E-301) Specification Sheet

<table>
<tr><td colspan="5">Heat Exchanger</td></tr>
<tr><td>Identification: Item
Item No.
No. Required</td><td colspan="2">Heat Exchanger
E-302
1</td><td colspan="2">Date: 25 March 2020

By: AIChE Design Group</td></tr>
<tr><td colspan="5">Function: Cool Mixed feed to Liquid with R-134a</td></tr>
<tr><td colspan="5">Operation: Continuous</td></tr>
<tr><td>Materials Handled:</td><td>Mixed Feed in</td><td>Mixed Feed out</td><td>R-134a inlet</td><td>R-134a outlet</td></tr>
<tr><td>Quantity (lb/hr)</td><td>51512</td><td>51512</td><td>51512</td><td>51512</td></tr>
<tr><td>Composition:</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hydrogen (H2)</td><td>0.83</td><td>0.83</td><td>0</td><td>0</td></tr>
<tr><td>Nitrogen (N2)</td><td>0.13</td><td>0.13</td><td>0</td><td>0</td></tr>
<tr><td>Ammonia (NH3)</td><td>0.04</td><td>0.04</td><td>0</td><td>0</td></tr>
<tr><td>R-134a</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>Temperature (°F)</td><td>562.1</td><td>-58</td><td>-97.6</td><td>-50</td></tr>
<tr><td colspan="5">Design Data:
Type: Air Cooler
Shell Pressure: 870.2 psia
Tube Pressure: 14.7 psia
Area: 585 ft²
MOC: Stainless Steel Shell/ SS Tube</td></tr>
<tr><td colspan="5">Utilities: 11290 kW municipal city electricity, 88,438.44 lbs R-134a refrigerant
Controls:
Tolerances:
Comments and Drawings: See Process Flow Sheet 3, pg# 19</td></tr>
</table>

Figure 15: Cooler (E-302) Specification Sheet

Pump			
Identification:	**Item** Item No. No. Required	Centrifugal Pump P-201 2	Date: *24 March 2020* By: *AIChE Design Group*
Function:	Compress O2		
Operation:	Continuous		
Materials Handled:		*H2O Feed*	*H2O Outlet*
Quantity (lb/hr)		7303	7303
Composition:			
Water (H2O)		1	1
Temperature (°F)		44.6	44.6
Flow Rate (gpm)		14.6	14.6
Design Data:	Pressure Inlet: 14.7 psia Pressure Outlet: 209.7 psia Flow rate: 575 gpm Material of Construction: Carbon Steel Power: 92 hp		
Utilities: 67.7 kW of municipal city electricity **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 2, pg# 17			

Figure 16: Pump (P-201) Specification Sheet

Electrolyzer				
Identification:	**Item** Item No. No. Required	*Alkaline Electrolyzer* R-201 # 125 Stacks		Date: *24 March 2020* By: *AIChE Design Group*
Function:	H2 Production by splitting H2O			
Operation:	Continuous			
Materials Handled:		*H2O feed*	*H2 gas outlet*	*H2O & O2 outlet*
	Quantity (lb/hr)	*7309*	*816*	*6493*
	Composition:			
	Water(*H2O*)	*1*	*0.00001*	*0.0115*
	Hydrogen (H2)	*0*	*0.99999*	*0*
	Oxygen (O2)	*0*	*0*	*0.9885*
	Temperature (°F)	*86*	*104*	*104*
Design Data:	Number of Cell: 20 Pressure: 267 psia Area: 5.4 ft^2 Faraday's Efficiency: 50.31% MOC:			
Utilities: 1457.6 kW municipal city electricity **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 2, pg# 17				

Figure 17: Electrolyzer (R-201) Specification Sheet

Conversion Reactor			
Identification:	**Item** Item No. No. Required	*Ammonia Conversion Reactor* R-301 1	Date: *25 March 2020* By: *AIChE Design Group*
Function:	Conversion of H2 and N2 into NH3		
Operation:	Continuous		
Materials Handled:		*H2,N2 Feed*	*H2 gas outlet*
Quantity (lb/hr)		*51512*	*51512*
Composition:			
Hydrogen (H2)		*0.85*	*0.83*
Nitrogen (N2)		*0.14*	*0.13*
Ammonia (NH3)		*0.01*	*0.04*
Temperature (°F)		*995*	*1155*
Design Data:	Pressure: 870.2 psia Volume: 287 ft^3 MOC: Stainless Steel		
Utilities:			
Controls:			
Tolerances:			
Comments and Drawings:	See Process Flow Sheet 3, pg# 19		

Figure 18: Conversion Reactor (R-301) Specification Sheet

Phase Separator			
Identification: **Item** Item No. No. Required	*O2-H2O Separator* T-201 1		Date: *24 March 2020* By: *AIChE Design Group*
Function: Separate O2 and H2O			
Operation: Continuous			
Materials Handled:	*O2 & H2O feed*	*O2 gas outlet*	*H2O outlet*
Quantity (lb/hr)	*6493*	*6487*	*6*
Composition:			
Water (*H2O)*	*0.0115*	*0.01*	*0.9999*
Oxygen (O2)	*0.9885*	*0.99*	*0.0001*
Temperature (°F)	*95*	*123.2*	*123.2*
Design Data: Pressure: 267 psia Height : 10 ft Diameter: 5 ft MOC: Carbon Steel Orientation: Vertical			
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Stream 2, pg# 17			

Figure 19: Separator (T-201) Specification Sheet

Phase Separator			
Identification: **Item** Item No. No. Required	*Ammonia-H2/N2 Separator* T-301 1		Date: *25 March 2020* By: *AIChE Design Group*
Function: Separate Product from Mixed Feed			
Operation: Continuous			
Materials Handled:	*Mixed feed*	*Recycle gas outlet*	*Ammonia product*
Quantity (lb/hr)	*51512*	*46440*	*5072*
Composition:			
Hydrogen (H2)	*0.83*	*0.85*	*0.0017*
Nitrogen (N2)	*0.13*	*0.14*	*0.0002*
Ammonia (NH3)	*0.04*	*0.01*	*0.9982*
Temperature (°F)	*-58*	*-58*	*-58*
Design Data: Pressure: 870.2 psia Height : 10 ft Diameter: 5 ft MOC: Carbon Steel Orientation: Vertical			
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 3, pg# 19			

Figure 20: Phase Separator (T-301) Specification Sheet

Pressure Vessel				
Identification:	**Item** Item No. No. Required	*Pressure Swing Adsorber Bed* V-101A/B, V102A/B, V-103A/B 6		Date: *24 March 2020* By: *AIChE Design Group*
Function:	Separate Nitrogen from Oxygen in Compressed Air Feed			
Operation:	Psuedo-Continuous			
Materials Handled:		*Compressed Air Feed*	*Oxygen Waste*	*Nitrogen Product*
Quantity (lb/hr)		*1648.76*	*380.8*	*1245.56*
Composition:				
	Nitrogen	*0.79*	*0.005*	*0.999*
	Oxygen	*0.21*	*0.995*	*0.001*
Temperature (°F)		*536*	*536*	*536*
Design Data:	Pressure: 87 psia Functional Height: 10.7 ft Diameter: 3.58 ft Material of Construction: Stainless Steel Internals: Carbon Molecular Sieve Orientation: Vertical			
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 1, pg# 11				

Figure 21: Pressure Vessel (V-101A/B, V-102A/B, V-103A/B) Specification Sheet

Pressure Vessel			
Identification:	**Item** Item No. No. Required	*Nitrogen Buffer Tank* V-104 #1	Date: *24 March 2020* By: *AIChE Design Group*
Function:	Regulate Varied Nitrogen Flow Rate		
Operation:	Continuous		
Materials Handled: Quantity (lb/hr) Composition:		*Combined Nitrogen Product* *3736.67*	*Buffered Nitrogen Product* *3736.67*
	Nitrogen	*0.999*	*0.999*
	Oxygen	*0.001*	*0.001*
Temperature (°F)		*536*	*536*
Design Data:	Pressure: 87 psia Functional Height: 34.1 ft Diameter: 11.35 ft Material of Construction: Stainless Steel Internals: none Orientation: Vertical		
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 1, pg# 11			

Figure 22: Pressure Vessel (V-104) Specification Sheet

Storage Vessel		
Identification: **Item** Item No. No. Required	*H2O Storage Vessel* V-201 1	Date: *24 March 2020* By: *AIChE Design Group*
Function: H2O Feed Storage		
Operation: Continuous		
Materials Handled:	*H2O Feed*	*H2O outlet*
Quantity (lb/hr)	7303	7303
Composition:		
Water (H2O)	1	1
Temperature (°F)	44.6	44.6
Design Data: Pressure: 64.7 psia Height: 5.25 ft Diameter: 1.75 ft Material of Construction: Carbon Steel Orientation: Vertical		
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 2, pg# 17		

Figure 23: H2O Storage Vessel (V-201) Specification Sheet

Storage Vessel			
Identification:	**Item** Item No. No. Required	*O2 Storage Tank* V-202 1	Date: *24 March 2020* By: *AIChE Design Group*
Function:	O2 gas Storage		
Operation:	Continuous		
Materials Handled:		*O2 gas inlet*	*O2 gas outlet*
Quantity (lb/hr)		6487	6487
Composition:			
Water (H2O)		0.01	0.01
Oxygen (O2)		0.99	0.99
Temperature (°F)		122	122
Design Data:	Pressure: 3192 psia Height: 4 ft Diameter: 2 ft Material of Construction: Carbon Steel Orientation: Horizontal		
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 2, pg# 17			

Figure 24: O2 Storage Vessel (V-202) Specification Sheet

Storage Tank			
Identification:	**Item** Item No. No. Required	*Ammonia Storage Tank* V-301 1	Date: *25 March 2020* By: *AIChE Design Group*
Function:	Ammonia Product Storage		
Operation:	Continuous		
Materials Handled:		*Ammonia Feed*	*Ammonia outlet*
Quantity (lb/hr)		5072	5072
Composition:			
Hydrogen (H2)		*0.0017*	*0.0017*
Nitrogen (N2)		*0.0002*	*0.0002*
Ammonia (NH3)		*0.9982*	*0.9982*
Temperature (°F)		*-58*	*-58*
Design Data:	Pressure: 870.2 psia Height: 117 ft Diameter: 58.5ft Material of Construction: Carbon Steel Orientation: Vertical		
Utilities: **Controls:** **Tolerances:** **Comments and Drawings:** See Process Flow Sheet 3, pg# 19			

Figure 25: Ammonia Storage Tank (V-301) Specification Sheet

Equipment Cost Summary

The equipment costs were estimated by using the Guthrie Method and everything was brought to its current 2020 cost by using the CE index.[14]

PSA separation beds were sized using the equations in the appendix mentioned previously. It was calculated that 3 pairs of tanks would be needed to handle the required throughput. Economically, to keep the cost of the separation beds low, it required the minimum amount of tanks. For each additional stream split, 2 more additional tanks would be needed. The overall cost of the separation tanks kept increasing with each stream split, meaning that the tanks had to be balanced with reasonable sizing and a minimal number of tanks. When sizing the tanks, L/D ratios of 3 and 4.5 were compared. The L/D ratio of 3 was consistently cheaper than L/D ratio of 4.5. The team determined that 3 feed splits, with an L/D ratio of 3, and 2 tanks per split, would be the most economical decision that satisfied heuristics and kept prices low. The price of the desiccant air dryer was estimated after converting the inlet air needed down to CFM units and then finding a mean price from multiple vendors. The silica gel was priced similarly, but to find the amount needed was after finding how much the air dryers themselves held. After this was found, the amount was multiplied by ten, as silica gel lasts about 2 years and this is over the course of 20 years.

The buffer tank was sized very similarly in concept as the adsorber tanks of the PSA system using equations seen within the appendix. The volume of the tank was a function of a standard residence time and the N_2 product flow rate as scaled to this particular ammonia process. This volume led to finding the overall height and diameter of the tank using the same L/D ratios, 3.0 and 4.5, mentioned in the PSA sizing. The overall C_{BM} cost of the buffer tank seemed to be noticeably less when the L/D ratio for the tank was 4.5. Furthermore, it was found that buffer tanks have an estimated functional life well beyond the necessary 20 year project life, meaning that the overall process would only require a one-time payment for this processing unit.

The alkaline electrolyzer capital cost was estimated based on approximate costing values provided by National Renewable Energy Laboratory (NREL) for a first-of-a-kind (FOAK) plant. NREL recommends using \$800 per kg of H_2 produced per day.[18] The designed electrolyzer produces approximately 8,879 kg of H_2 per day, which means each electrolyzer cell produces 3.58 kg per day. However, the cost analysis for a modular plant is done differently then the stick-built models.

$$\boxed{k_n = k_1 n^{\log_2 p}} \tag{9}$$

$$\boxed{K(N) = \sum_1^N k_n} \tag{10}$$

For a FOAK plant, the Equation 9 and 10 are used to determine the cost of a modular unit. In order to properly cost the electrolyzer, we needed to determine the optimum number of cells we need to place in parallel to make up the electrolyzer stacks. We varied the number of cells per stack from having only 10 cells per stack to 50 cells per stack and used the Equation 9, which provides the cost of the n^{th} module where k_1 is the cost of the first module, to estimate the purchase cost of the electrolyzer individual stacks. Next, the Equation 10 was used to determine the total purchase cost for the various number of electrolyzer stacks.

The calculated purchase cost was in 2005 dollars. As a result, we had to use the CE index for 2005 and 2020 to bring the money back to 2020. For 2005, we used a CE index value of 467.2 and for 2020, we used a CE index value of 592.1.[19] Once the purchase cost was calculated and converted into 2020 dollars, we proceeded to determine the operation cost. Matlab was used to determine the power required for these various numbers of cells in order to calculate the operation cost. Table 19 below summarizes the electrolyzer optimization calculations.

Table 19: Electrolyzer Optimization

# of Cells per Stacks	# Electrolyzer Stacks	Total Purchased Cost, 2020	Operating Cost	Total
10	249	$2,222,974	$1,594,172	$3,817,146
20	125	$2,764,398	$800,271	$3,564,668
30	83	$3,120,666	$531,409	$3,652,075
40	63	$3,432,525	$403,375	$3,835,899
50	50	$3,648,642	$320,141	$3,968,783

According to the purchase cost alone, having 249 stacks seems more economical, however, the operation cost is very high. Once the operation cost for each unit was accounted for, we found the 125 stacks with 20 cells in parallel to be the optimum number for the alkaline electrolyzer. We also plotted the results from Table 19 to visualize the data. The minimum value in the Figure 26 occurs for 125 electrolyzer stacks with a cost of $3.56 million dollars, which includes both the purchase and the operation cost.

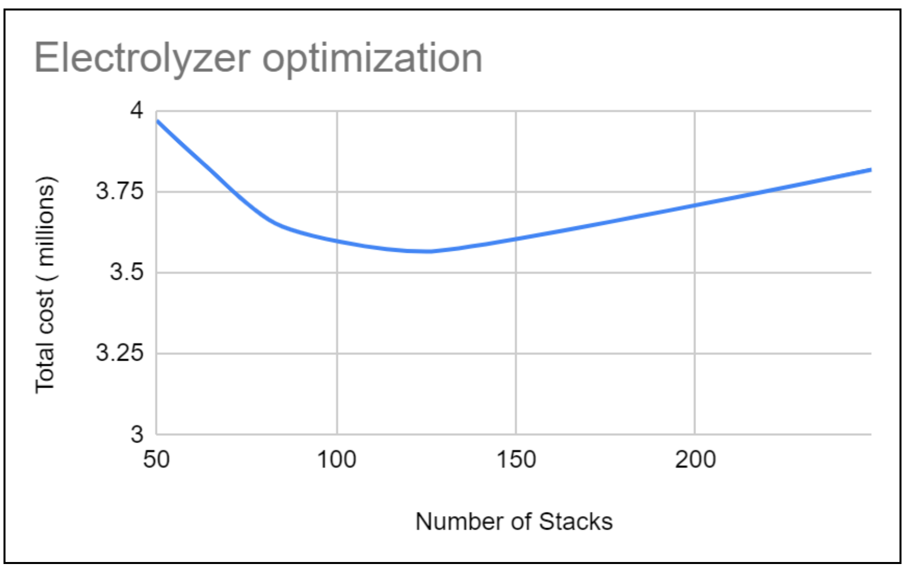

Figure 26: Electrolyzer Optimization

Once we determined the 125 electrolyzer stacks to be the most economical option, estimated the cost of the electrolyzer to be \$2,764,398. The electrolyzer stacks have a 7 year life, as a result, they need to be replaced every 7 years. The replacement cost for the electrolyzer stacks are 25% of the initial capital cost.[20] As a result, an additional \$691,099 dollars needs to be invested every 7 years.

$$\log_{10} C_p^0 = K_1 + K_2 \log_{10} A + K_3[\log_{10} A]^2 \tag{11}$$

The cost of the separator, storage vessels, heat exchangers, pumps, and compressor for all units were estimated by using costing values provided in the Turton textbook.[11] These equipment uses a similar method to estimate the total installed cost. The standard purchase cost for all the equipment listed above is determined by using Equation 11. The storage vessels, ammonia reactor and separator standard purchase cost were estimated based on their volumes while the pumps and compressors were calculated based on their powers, and the heat exchangers were determined by surface area available for heat transfer.

$$F_p = \frac{\frac{(P+1)D}{2[850-0.6(P+1)]} + 0.00315}{0.0063} \tag{12}$$

$$log_{10} F_p = C_1 + C_2 log_{10} P + C_3[log_{10} P]^2 \tag{13}$$

$$C_p = C_p^0 F_m F_p \tag{14}$$

$$C_{BM} = C_p^0 F_{BM} = C_p^0(B_1 + B_2 F_M F_P) \tag{15}$$

Equation 11 provides only the base cost, which does not account for the pressure factor, F_P. In order to account for the pressure factor in C-101, C-201, C-301, P-201 A/B, E-201, E-202, E-301, and E-302, we used Equation 12. Similarly, we used Equation 13 to determine F_p for R-301, T-201, T-302, V-101, V-201, V-202 and V-301. The purchase cost was then calculated by using Equation 14 which utilizes F_p and the material factor, F_m, to provide a better estimation.

Finally, the total installed bare module cost for each of the equipment was calculated by using Equation 15. Table 20, shown below, presents the electrolyzer unit equipment cost.

The stream compressor was made to compress the mixed streams of incoming hydrogen and nitrogen from the PSA, electrolyzer, and recycle stream. To retrieve the K values, the Turton textbook[11] was referenced, and plugged into Equation 11 along with the power, which could be retrieved from HYSYS. After this, the capital cost could be found and brought to 2020 values. The two heat exchangers were cost differently. One needed both shell and tube to be occupied by streams important to the process, and the other's only priority was to cool the product stream. The areas of the two pieces of equipment were able to be determined by obtaining the duty of each, and plugging those into Equation 11 with the internal energy and calculated LMTD's. The reactor, storage tank and phase separator were costed similarly to the compressor, just using their specific K and C values.

Table 20: Major Equipment Cost

Equipment	Cost (CBM_{2020})/unit
F-101	$636
C-101	$14,202
V-101A/B	$97,196
V-102A/B	$97,196
V-103A/B	$97,196
V-104	$1,503,595
R-201	$2,764,398
T-201	$270,305
E-201	$162,996
E-202	$297,690
P-201 A/B	$135,862
C-202	$1,094,475
V-201	$348,826
V-202	$48,682
R-301	$61,119
T-301	$2,884,283
V-301	$5,768,569
E-301	$165,548
E-302	$125,751
C-301	$1,094,475
Total, CBM_{2020}	$18,473,375

Fixed Capital Investment Summary

The capital costs associated with this project include all of the initial investments for equipment and administrative costs. The project has a plant life of 20 years. Operating conditions required for each step of the process and equipment sizing were the chief components to determine the cost equipment. The Table 20, summarizes all the major equipment cost, which contributes towards the fixed capital investment necessary during the plant construction and startup period. The anhydrous ammonia plant designed for this project is a modular plant, and a hybrid between unitary modular and a parallel modular plant. The modularity of the plant affects the fixed capital investment, as the equipment for a FOAK plant will cost differently with bulk equipment purchases, as discussed in the equipment cost summary section on page 56.

Following the unitary modular model, the plant is broken down into three units: PSA unit, Electrolyzer unit, and the Ammonia synthesis unit. We have decided on these three units based on the processes the reactants H_2 and N_2 are produced and combined to make the anhydrous ammonia. The N_2 gas is produced through PSA, as a result it is separated into its own unit. Similarly, H_2 is produced through electrolysis of water and is separated into its own unit. Finally, the two reactants are combined to make NH_3 by using the Haber-Bosch process, hence, it is also a separate unit. The PSA unit and the electrolyzer unit are further divided into subsections by using the parallel manufacturing paradigm.

The PSA unit consists of a dry air filter, F-101, compressor, C-101, PSA beds, V-101 A/B, V-102 A/B, V-103 A/B, and the buffer tank, V-104. The PSA unit boundary is defined by the air inlet to F-101 and the N_2 outlet from V-104. Within the PSA unit, the 3 adsorption bed pairs are placed in parallel to each other to produce the required amount of N_2 gas. The PSA unit PFD is shown in Figure 2.

The Electrolyzer unit consists of water storage vessel, V-201, centrifugal pump, P-201 A/B, heat exchangers, E-201 and E-202, the alkaline electrolyzer, R-201, O_2-H_2O separator, T-201, O_2 compressor, C-201, and the O_2 storage vessel, V-202. The alkaline electrolyzer is inherently modular as discussed previously due to its ability to stack up by placing cells parallel to each other in order to expand capacity. The electrolyzer unit boundary starts with the water inlet to V-201 and concludes with the H_2 outlet from the electrolyzer and downstream separation and storage of O_2 byproduct at V-202. The Electrolyzer unit PFD is shown in Figure 3.

The Ammonia synthesis unit consists of a compressor, C-301, heat exchangers, E-301 and E-302, ammonia reactor, R-301, separator, T-301, and the ammonia storage vessel, V-301. The unit boundary is defined by the reactant inlet stream to the compressor and the storage of anhydrous ammonia in V-201. The Ammonia unit PFD is shown in Figure 4 on.

Table 21 presents the capital cost for each unit and the total fixed capital investment necessary for the project.

Table 21: Fixed Capital Investment (FCI)

Modular unit	Capital Cost
PSA unit	\$1,810,021
Electrolyzer unit	\$5,123,232
Ammonia synthesis unit	\$11,540,122
Total Fixed Capital Investment	\$18,473,375

Safety, Health, and Environmental Considerations

A typical ammonia process brings about the presence of many biological, chemical, mechanical, and environmental hazards. If this process is expected to run its full 20 year project life with minimal disruptions and ensured safety, these hazards must be considered and mitigated. The specific hazards within the process to be considered are those regarding material processing streams, the processing equipment, impact on the environment, and impact on operators and the community.

Within this process there are two main natural components used that are non-hazardous under typical STP conditions including water and air; however, the derivatives of these components that flow through this process can be very dangerous. For the material process streams within the system there were a few areas in which safety measures were considered and implemented; these areas included the individual chemical characteristics of the material streams, their nature under varying physical conditions, and their interaction with other present chemical/material streams. Many of the equipment safety measures/hazards accounted for are consistent and inherent standards of the industry and should be acknowledged.

All of these hazardous attributes of a chemical plant process have been assessed using standard safety analysis measures. These types of analyses used include tables over material properties, process chemical interaction, inventory of hazardous materials, known process/equipment hazards, etc.

Table 22: Material properties

Chemical	MW (lb/lbmol)	Boiling Point (°F)	LFL (% by volume of air)	UFL (% by volume of air)	Autoignition Temperature (°F)	MOC (Vol %)
Water, H_2O	18.02	212.0	N/A	N/A	996.8	None
Nitrogen, N_2	28.02	-320.4	N/A	N/A	None	None
Hydrogen, H_2	2.02	-423.0	4.0	75	1085.0	5.0
Oxygen, O_2	32.00	-297.4	N/A	N/A	806.0	＞0.0
Ammonia, NH_3	17.03	-27.9	15	28	1,203.8	15.0

	Ammonia, Anhydrous			
Oxygen	**Incompatible** -Generates gas -Intense/explosive reaction	Oxygen		
Hydrogen	**Compatible**	**Incompatible** -Corrosive -Flammable -Gas and heat generation -Intense/explosive reaction -Unstable when heated	Hydrogen	
Water	**Caution** -Generates heat	**Incompatible** -Corrosive -Gas and heat generation -Toxic	**Compatible**	Water
Nitrogen	**Compatible**	**Compatible**	**Compatible**	**Compatible**

Figure 27: Interaction Matrix[21]

Table 23: Inventory of Hazardous Materials

Component	Hazards	Stream/Location of Hazardous Material Presence	% Concentration of Hazardous Material in Stream (Mass Basis)	Amount: Mass Flow Rate - Volume Per Tank
Ammonia, NH_3	Potentially largely exothermic if added to water* May combust in the presence of an open flame Eye irritant Inhalation may cause irritation of the respiratory tract; potentially fatal. [22]	28, 29, 30	6.20%	3194.0 lb/h
		32	99.80%	5068.5 lb/h
		Storage	99.80 %	23.70 barrel/ tank
Oxygen, O_2	Highly flammable. Chemical runoff may result in spontaneous fires. Inhalation may cause nausea or dizziness. [23]	1	23.26%	1146 lb/h
		2, 3	23.27%	1146 lb/h
		4, 5, 6	23.27%	382 lb/h
		7, 8, 9	99.56%	380 lb/h
		18, 20	99.35%	6451 lb/h
		21, 23, 24	99.43%	6450 lb/h
		22	16.67%	1.0 lb/h
		Storage	99.4%	16.2 barrels per tank

Table 24: Known Process and Equipment Hazards

Process unit	Hazards	Solution
C-101	Pressure Temperature	Pressure Safety Valve Insulation
V-101 A/B	Over pressured/Rupture Temperature	Pressure Safety Valve Insulation
V-102 A/B	Over pressured/Rupture Temperature	Pressure Safety Valve Insulation
V-103 A/B	Over pressured/Rupture Temperature	Pressure Safety Valve Insulation
V-104	Over pressured/Rupture Temperature	Pressure Safety Valve Insulation
V-201	Pressure	Pressure relief valve
P-201 A/B	Pressure	Stronger materials
E-201	Pressure Temperature	PPE
R-201	Heat generation Electrical hazard	Cooling Jacket, active alarms and sophisticated control system
T-201	Pressure Temperature	Pressure relief system PPE
C-201	Pressure Temperature	Isolated zone. PPE
E-202	Temperature	PPE
V-202	1.Pressurized vessel can rupture and explode 2. O_2 storage	Minimization of inventory
C-301	High Pressure	Pressure Safety Valve Insulation
E-301	1. Pressure 2. Temperature	Stainless steel manufacture
R-301	1. Pressure 2. Temperature	Stainless steel manufacture
T-302	1. Pressure 2. Suffocation risk	Keep in open environment

Safety Assessment Results:

From Table 22, made using reference material from the GPSA handbook,[19] various basic properties of the chemicals utilized within this ammonia production plant may be seen. Among the various listed properties in the table are the LFL, UFL, autoignition temperature, and MOC. The lower and upper flammability limits (LFL and UFL, respectively) indicate the minimum and maximum ratio of the gaseous component to air that can potentially burn. Where the flammability limits mark the fire hazard ranges of a component mixed with air, autoignition temperature makes note of the temperature at which a lone component might catch fire. These previous properties infer the ranges at which a component may ignite; whereas, the limiting or ‘minimum’ oxygen concentration (MOC) gives the lowest volumetric concentration of oxygen in a binomial mixture with the component needed to potentially combust. The process is not anticipated to operate near the auto ignition temperature of any of the components. MOC levels are all below ambient oxygen content levels, meaning that the process is readily capable of combustion, and it is imperative to maintain containment of the process chemicals. Ammonia and hydrogen gas are the most flammable materials in the process and must be monitored.

The “Interaction Matrix,” seen as Figure 27, displays the main components within the plant process and how each reacts when put in contact with each other individual component of the process. From this information it is indicated that ammonia should not be put in contact with oxygen at any point. This mixture of NH_3 and O_2 is described as “incompatible,” meaning that their combination may result in hazardous conditions. These hazardous conditions are indicated in the cross section box of ‘Ammonia, Anhydrous’ and ‘Oxygen,’ being the generation of a gaseous substance and a potentially intense or explosive reaction. Another potentially hazardous mixture is that of ammonia and water, which can be seen under the mixture’s cross section box with the label “caution.” This label indicates that the combination of these substances, while not inherently hazardous, may potentially bring about hazards under certain conditions. In this case of water and ammonia, the mixture may generate a very large amount of heat if it is either combined in large quantities or is itself heated. The other potential combination hazards from any two process chemicals may be seen under the cross section box of the two components.

The two main hazardous components of this process, NH_3 and O_2 , also happen to be the two components that would be stored outside of the process; Table 23 gives an overview of the innate hazards of these substances as well as the quantities in which they may be seen within the plant/process. This table is referred to here as the Inventory of Hazardous Materials (IHM), and is required for any given chemical plant expected to contain hazardous substances so as to allocate dangerous chemicals as they might regularly appear in the plant. While these hazardous materials may be seen in trace amounts throughout the process, the IHM only accounts for those locations where the select substances have a molar concentration of 5.0% or higher. The IHM indicates the expected location of these materials, indicating either stream number if the specific quantities are within the process, or labeled "Storage" for the amount of stored final product material following the process. In addition to giving the location of these hazardous materials, the IHM also outlines the specific hazards associated with each material, the concentration of the material within each listed location, and the specific quantity/flow rate of the material within the listed location.

Table 25 shows the various processing units and their associated hazards and potential solutions. Some consistent hazards seen throughout the process are those regarding instances of high pressure and temperature. Equipment insulation, and standard pressure safety valves must be used to mitigate these factors.

Table 25: Hazard Identification Summary

Source	**Hazards**
Material Properties	High purity of NH_3 or mixture with high concentration of O_2 may result in ignition or combustion. For the process to run properly without additional hazards from chemical properties, all intermediate (excluding inlet and product outlets) stream temperatures within the process should be well within the range of -297.4°F to 1,203.8°F Oxygen has a relatively low autoignition temperature of 806°F Exposure of slight amounts of gaseous ammonia and hydrogen into air may result in flammable substances. Sufficient oxygen contact with ammonia or hydrogen (binomial mixture of <15.0% O_2 by vol. and <5.0% O_2 by vol., respectively) may result in combustion
Initial Interaction Matrix	Generation of heat or gas Flammable substances Explosion reactions Corrosive substances Toxic substances Potential runaway reactions
Inventory Estimates	A single day's operation generates 50 tons of NH_3 A single storage tank contains 55 tons of NH_3 A single storage tank contains 16.2 barrels O_2 per tank, maximum of 24 storage tanks O_2
Process Technology, Equipment & Operating Conditions	The ammonia reaction takes place at 1155ºF and 870.2 psia. High Temperature High Pressure Rotating Machinery

Table 26 : Potential Consequence summary

Potential Consequence summary							
Hazard		Equipment Damage	Environmental Compliance	Loss of Life	Disruption of Other Business Units	Legal/ PR	Community Impact
1	VCE* (O_2)	High	N/A	High	High	High	Medium
2	O_2/H_2 Recombination Reaction	Medium	N/A	Low	Medium	Low	Low
3	O_2/H_2O Reaction	Medium	N/A	Medium	Low	Low	Low

*VCE - Vapor cloud explosion

Existing safeguards:

Each of the processes within the project does require pressure relief valves. Most are given their location for maintenance if any piece of equipment needs to be repaired or replaced. The standard PPE of closed toed shoes, long sleeve shirts, pants, safety helmets, and safety glasses/goggles should be worn at all times within the plant. Areas such as around the ammonia synthesis portions would also require respirators in case of leaking. Also due to the safety hazards associated with each of the components, the plant's equipment is outside to minimize components saturating the air and causing suffocation.

Additional Safeguard Evaluations and/or Requirements:

Additional safeguards that would be implemented would be gauges to measure readouts in control rooms to make sure that equipment was running properly. Fences would be put up around the perimeter with security and surveillance to assure that the equipment and civilians are safe around the plant at all times. Guardrails would be implemented with every bit of scaffolding and stairs to maneuver around the equipment throughout the plant safely.

Safety Assessment Summary

There are no catastrophic failure hazards that could potentially terminate the project. There are process hazards present in the project, with potentially major consequences. Similarly there are no immediate hazards present in the project.

The hydrogen extracted from the alkaline electrolyzer is highly flammable. There isn't exposure to air once the hydrogen is extracted. Hydrogen and ammonia can explode when exposed to a flame at high pressures. Ammonia is highly flammable. There are no open flames around the plant, and all pieces of equipment are sealed, but due to the conditions held during the process, it is at an elevated risk at which precautions must be made for.

None of the components handled within the plant are toxic or very corrosive. But it would be unsafe if oxygen, hydrogen or ammonia were to leak in high volume. hydrogen and ammonia can suffocate and oxygen enriched areas can also be hazardous, these effects are mitigated by having the process occur outdoors.

The entire process is relatively safe considering the industrial scale of the process. The plant is designed with the proper faculty, and safeguards to mitigate most possible risks. The ammonia reaction does take place under some extreme parameters, which would be the highest risk in the plant. While leaks of the various components would be dangerous under normal circumstances, the open plant all but eliminates major leak threats.

Table 27: Inherently Safer Design Application Summary

Hazard	Inherent Safety Concept	How Incorporated in Design
Extremely reactive and highly flammable product stored on site	Attenuation	Storing product in many separate containers as opposed to fewer
Ammonia plant generates a considerable amount of greenhouse gasses	Substitution	Power supplied via renewable resources such as wind farms. Method of ammonia synthesis does not create greenhouse gas byproducts.
Oxygen enriched environment	Simplification	Nitrogen production, and its concentrated oxygen waste is vented outdoors, where dilution is immediate.

Opportunities for Additional ISD:

While this ammonia production plant relies mainly on clean and naturally occurring resources, there are still many notable safety concerns that operators must be advised of including chemical, mechanical, and environmental hazards.

Within this process we rely on the creation and flow of multiple gaseous components under intense conditions. Any of these gases can be hazardous under high concentrations as they may cause asphyxiation. High purity oxygen can be seen within the process and is another noteworthy hazard due to its high flammability and combustion risk.

Among the more hazardous chemical compounds involved in our process is anhydrous ammonia. Ammonia is a highly flammable gas. Since it is stored in highly pressurized vessels, the ammonia also has a moderate explosive risk that could occur, should rupture happen. Since the process is also at the industrial level, high amounts of ammonia are constantly being made and if a leak were to happen, the ammonia can displace oxygen which might encourage an open air environment, or a very well circulated indoor facility.

In addition to the many chemical hazards present within our process, there also exists physical hazards that can be linked to the many apparatuses that comprise our process. One such hazard comes from the reactor which must be heated to 1155ºF and run under high pressure 870.2 psia. It is important to keep processing units running at the specified operating conditions (flow rates, temperatures, pressures) as deviating from these values could potentially result in fracturing equipment, and likely leakage of hazardous chemicals. For this reason, regular maintenance and inspection of processing equipment is expected.

In consideration of all these hazardous conditions, proper personal protective equipment (PPE) is required of all employees, civilians, and other personnel that are to be located on the premises at any time, especially for those that more closely work with these operations. Required PPE to be worn by personnel include closed toe shoes, long pants, long sleeve shirts, safety glasses/goggles, hard hats, and in certain parts of the plant, masks may be necessary. Throughout the process compounds are heated to dangerous temperatures; as such, it is recommended that anyone physically interacting in or around the heated equipment wear properly insulated (leather or Nomex) thermal safety gloves. In the event of gaseous leak, respirators should be located on the premises.

Process Safety Considerations

This process focuses heavily on using natural resources and integrating them completely within the design of synthesizing ammonia, thus allowing waste streams to be considerably negligible. Process hazards are mainly considered in the containment of these components. Throughout this process oxygen is emitted, and seeing as how many hazards can arise from the combination of oxygen with many of these substances, proper containment of all process chemicals must be adhered to. In addition to avoiding contact between oxygen and other processing materials, so too must it be ensured that open flames are kept far away from any O_2 sources. This process therefore avoids usage of any open flames partially due to this precaution.

Other Important Considerations

Other gases required to be separated from the atmosphere may need to be taken into account, with the local air composition in the Minnesota River Valley. Hydrocarbons, volatile organic compounds, inert gases and other potential vapors may have a significant impact that needs to be considered when designing the PSA unit, and its filter.

For our process we assumed our natural resources, air and water, to have an ideal standard composition. For instance, the air that we used in our calculations was made to only consist of nitrogen, oxygen, and water; realistically, however, real air is likely to contain trace amounts of other chemical components such as argon and water vapor. For our electrolyzer the water was assumed to be 100% pure. The presence of these components in both the air and water may likely cause slight deviations in values calculated within this report; these deviations would only be expected to grow and make the process more inefficient as the process is scaled up.

Manufacturing and Operation Cost (excluding capital requirement)

The manufacturing and operation cost is an important parameter that determines the economic viability of a plant. The operating costs were obtained from the design and optimization calculations from HYSYS, Matlab and hand calculations. Raw materials cost (RM), utility cost (UT), operating labor cost (OL), fixed capital investment (FCI), and waste treatment are the five key elements that contribute to the calculation of total manufacturing cost. Four, excluding fixed capital investment, major cost contributors are discussed in detail in this section.

The capital requirement for this project is discussed above in greater detail in the Fixed Capital Investment Summary section on page 62. However, it is being utilized in this section to calculate the total manufacturing cost, which will be discussed below.

The service factor is a crucial factor that affects three major parameters, raw material cost, utility cost, and operating labor cost, used to estimate the total manufacturing and operation cost. The plant was assumed to operate 23 hours a day for 365 days. In order to account for lost workdays and required downtime for equipment repairments, the service factor was calculated to be 0.96. The service factor is accounted for during the raw material cost, utility cost, and operating labor calculation.

Raw Material Cost

Raw materials are a crucial aspect of any processes that produce valuable products. In the ammonia synthesis Haber-Bosch process, we are using nitrogen generated from air and hydrogen generated from water to produce anhydrous ammonia. Hence, air and water is considered to be raw materials However, we don't have to pay for air as it is available in the environment free of charge, which means water used in the electrolyzer is the only raw materials that we have to account for. The prices for raw materials were found through research in areas around the Minnesota River Valley[25]. The cost associated with the raw materials are presented in Table 28.

Table 28: Raw Material Cost

Raw Materials	Amount	Cost
Water	874 gallons/hr	$0.00194/gallons

Utility Cost

The utility cost for the ammonia plant is calculated based on the operating conditions from the PFDs discussed previously. The plant uses two major utilities: electricity and water. The utility specifications and prices are provided on page 20 in the Energy Balance and Utility Requirement Section. Table 29 provides the annual utility cost for the major equipment.

Table 29: Annual Utility Cost

Electricity	Cost	Unit
P-201 A/B	$36248	$/yr
C-101	$2,878	$/yr
C-201	$200,617	$/yr
C-301	$5,753,866	$/yr
R-201	$800,271	$/yr
T-201	$10,067	$/yr
E-302	$6,198,583	$/yr
Water	Cost	Unit
E-202	$33,524	$/yr

Operating Labor

Operating labor is a key parameter that contributes to the total manufacturing cost of a plant. It was calculated by using Equation 16, where N_{OL} is the number of operators required per shift, P is the number of particulate processing steps and N_{np} is the number of nonparticulate processing steps.

$$N_{OL} = \left(6.29 + 31.7P^2 + 0.23N_{np}\right)^{0.5} \tag{16}$$

N_{OL} was calculated assuming the number of particulate processing steps as zero and the number of nonparticulate processing steps as 12, excluding pumps and process vessels. The total number of operators required to operate the ammonia plant was determined to be 14 by using N_{OL} and the minimum number of required operators. Assuming 1 operator works 8 hours per shift for 5 days a week and 49 weeks per year, the minimum required labor was calculated to be 5 operators per shift. Using data from the United States Department of Labor, the average salary for plant operators in Minnesota was found to be $55,806.00/year, which was later used to calculate the total cost of operating labor.

Once all five elements were determined, the total manufacturing cost was calculated by using Equation 17.

$$\textit{Total manufacturing cost} = 0.18FCI + 2.73COL + 1.23CUT + 1.23CWT + 0.23CRM \tag{17}$$

The total manufacturing cost for the ammonia plant was determined to be approximately $21.5 millions per year, which makes the designed ammonia plant highly expensive to operate. Table 30 provides the total manufacturing cost and the associated cost with the five parameters discussed above.

Table 30: Total Manufacturing Cost

Operating Cost	$/year
Raw Materials Cost	$14,219
Utility Cost	$13,036,053
Operating Labor Cost	$781,284
Fixed Capital Investment	$18,472,739
Waste Treatment Cost	$0.00
Total Manufacturing Cost	$21,509,831

Economic Analysis

To find the revenue of the process, the amount of the product stream needs to be multiplied by the price of ammonia. Finding the amount of product stream necessary was given by the design document, but the exact value was given by HYSYS. The raw material costs were found from the aforementioned researched price per volume multiplied by the amount necessitated by each designs' requirements. All of this information works the same for the oxygen product accumulated earlier in the overall process.

The cash flow table shown in Figure 28 shows how the revenue made from selling both product streams compares to the manufacturing and operating costs spread over the life of the project. This also includes replacements of equipment throughout the life, as well the taxable income each year. Once these values are all input, the more important analysis can occur with discounting the cash flow, and determining the NPV and DCFROR to determine if the project was profitable.

Project Title: Ammonia Production

Corporate financial situation: Stand alone

Minimun rate of return, i* = 0.08 or 8%

1=$1,000,000

End of Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Production tonnes Anhydrous Ammonia	0.00	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94	52.94
x Sales Price, $/metric ton	0.00	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62	503.62
Production tonnes Oxygen (O2)	0.00	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61	70.61
Sales Price $/metric ton	0.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Sales Revenues	0.00	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37
(+) Salvage Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(-) Royalties	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Revenues	0.00	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37	9.37
(-) Other Op Costs	0.00	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)	(21.54)
(-) Depreciation	0.00	(1.31)	(0.96)	(0.13)	(0.17)	(2.30)	(2.51)	(0.80)	(0.86)	(0.16)	(1.73)	(2.34)	(2.44)	(0.48)	(0.69)	(2.04)	(1.93)	(1.91)	(2.11)	(0.09)	(0.44)
(-) Amortization	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(-) Depletion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(-) Loss Forward	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(-) Writeoff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(1.67)	0.00	0.00	(0.14)	0.00	0.00	0.00	(0.42)	0.00	0.00	0.00	0.00	(0.54)
Taxable Income	0.00	(13.49)	(13.14)	(12.30)	(12.35)	(14.47)	(14.69)	(12.98)	(14.70)	(12.33)	(13.91)	(14.66)	(14.61)	(12.66)	(12.86)	(14.63)	(14.11)	(14.08)	(14.29)	(12.26)	(13.16)
(-) Tax @ 25%	0.00	(3.37)	(3.28)	(3.08)	(3.09)	(3.62)	(3.67)	(3.24)	(3.68)	(3.08)	(3.48)	(3.66)	(3.65)	(3.16)	(3.22)	(3.66)	(3.53)	(3.52)	(3.57)	(3.07)	(3.29)
Net Income	0.00	(16.86)	(16.42)	(15.38)	(15.44)	(18.09)	(18.36)	(16.22)	(18.38)	(15.42)	(17.38)	(18.32)	(18.27)	(15.82)	(16.08)	(18.29)	(17.64)	(17.61)	(17.86)	(15.33)	(16.45)
(+) Depreciation	0.00	1.31	0.96	0.13	0.17	2.30	2.51	0.80	0.86	0.16	1.73	2.34	2.44	0.48	0.69	2.04	1.93	1.91	2.11	0.09	0.44
(+) Amortization	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(+) Depletion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(+) Loss Forward	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(+) Writeoff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	0.14	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.54
(-) Working Capital	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(-) Fixed Capital	(18.47)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(0.69)	0.00	0.00	(0.29)	0.00	0.00	0.00	(0.69)	0.00	0.00	0.00	0.00	0.00
Cash Flow	(18.47)	(15.55)	(15.46)	(15.25)	(15.26)	(15.79)	(15.85)	(15.42)	(16.54)	(15.26)	(15.65)	(16.13)	(15.83)	(15.34)	(15.39)	(16.53)	(15.70)	(15.70)	(15.75)	(15.24)	(15.47)
Discount Factor, (P/Fi*,n)	1.00	0.93	0.86	0.79	0.74	0.68	0.63	0.58	0.54	0.50	0.46	0.43	0.40	0.37	0.34	0.32	0.29	0.27	0.25	0.23	0.21
Discounted Cash Flow	(18.47)	(14.40)	(13.26)	(12.11)	(11.22)	(10.75)	(9.99)	(9.00)	(8.94)	(7.63)	(7.25)	(6.92)	(6.29)	(5.64)	(5.24)	(5.21)	(4.58)	(4.24)	(3.94)	(3.53)	(3.32)
NPV @ i* =	(172)	not attractive																			
DCFROR =		8%																			
Equation for DCFROR																					
result	Not attractive																				

Figure 28: Cash Flow Table

DCFROR Analysis

Upon completion of the cash flow table, the DCFROR was attempted to be calculated. Due to the excess expenses without sufficient revenue, the project does not have a profitable year during the anticipated life. Due to having yearly losses, the DCFROR is not capable of being calculated. This is a major red flag for the economic feasibility of the project.

NPV Analysis

The project is not profitable any of the 20 years of its projected life. This creates a highly negative NPV. Since we have no positive years, the sensitivity analysis could not be done over the DCFROR. This caused the NPV to take its place in the sensitivity analysis. A negative NPV indicates that the project is not profitable.

Sensitivity Analysis

In an effort to spot any variabilities within the project to make it profitable, a sensitivity analysis was performed on the working capital, product pricing, and utility costs. Each of these factors contributed largely to the profitability to the project, and prices for everything constantly changed throughout time.

According to the capital cost sensitivity variation data, the fixed capital investment varies from -15% to +15%.[26] Altering the fixed capital investment would have the least effect on the NPV. While lowering the fixed capital investment by 15%, the NPV only changes by 2%. Compared to utilities' costs lowering the NPV by 28% when lowered by the same percent. The reason for the fixed capital cost altering having such a small effect on the NPV is that the fixed capital investment is only pertaining to the initial cost of the project. The other two parameters analyzed affect the yearly amount earned or cost over the life of the project.

The sell price of the ammonia largely impacts the profitability of the project. If the product is not valued, then it is very hard to rationalize the creation of a process to make the process. While the scope of changing the product price by up to 15% either way did not make the project profitable, it did make a moderate impact on the NPV. For this project to overcome the hurdle rate, the ammonia price per ton would have to increase by around 150% which is not very likely within the coming years.

While utility pricing is a major impact to the entirety of the process, altering the utility costs alone would not make the project profitable. Only after a nearly 82% reduction in utility cost would the project begin to turn a profit. Furthermore, the utility cost would need to be reduced by over 94% for the project to overcome the recommended hurdle rate by cheaper utility cost alone. Testing the NPV variation, by changing the utility costs by 5, 10, and 15 percent, the NPV was altered by multiples of 6 percent. Though the utility costs being lowered seems to have the largest effect on the NPV.

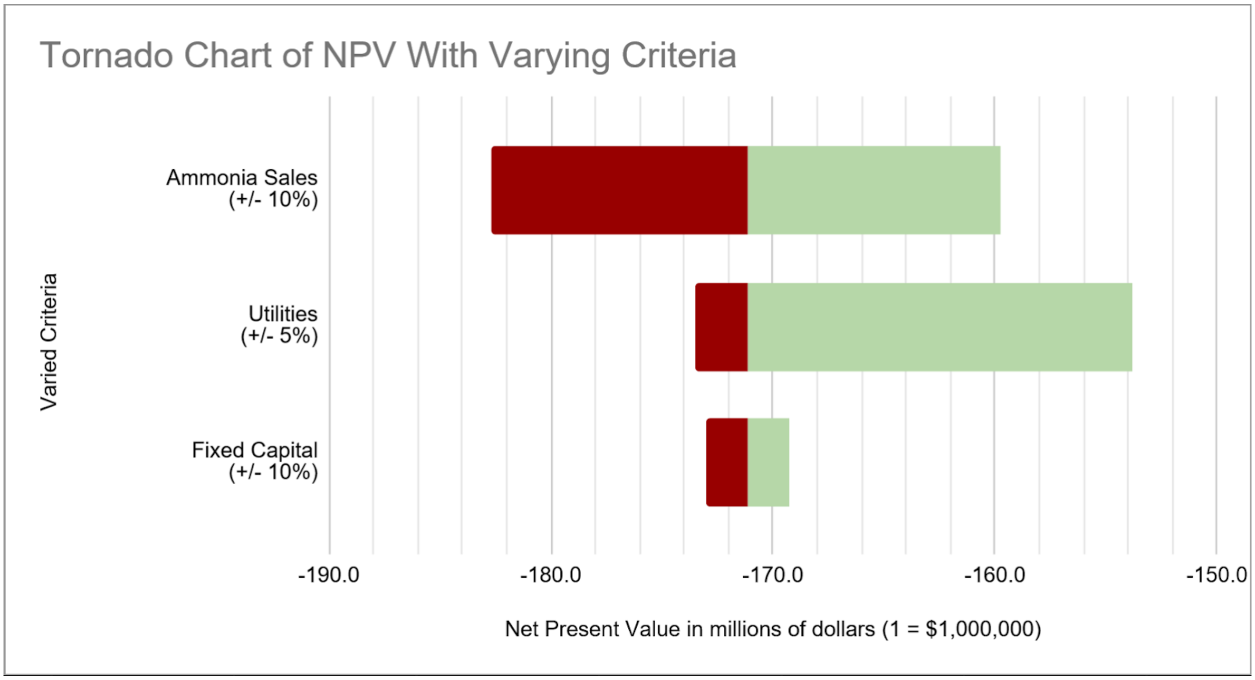

Figure 29: Tornado Chart

[*Base NPV of -171,137,754. ammonia has 10% variance (-10% : -182,658,866 +10%: 159774038), Utilities has 5% (-5%: -153,834,740 +5%: -173,513,185) , FixCap has 10% (-10%: -169,290,480 +10%: -172,985,028)]

Conclusions and Recommendation

The project was determined incapable of producing profit with the design parameters utilized. The hydrogen extraction was achieved through designing an alkaline electrolyzer on HYSYS. The nitrogen production was done through a pressure swing adsorption system designed by hand. Finally the ammonia synthesis was also designed through HYSYS. These design choices were to maximize the "green" engineering, and determine if the project was profitable. The next steps should be to determine what changes should be made to increase profits at the expense of increasing the carbon footprint of the plant. There are significant utility costs found in the ammonia synthesis unit, and the electrolyzer, these units may be capable of being replaced with cheaper less "green" options that may swing the project into profits.

The project began with significant research into alternative “green” engineering solutions to ammonia fertilizer production. The traditional ammonia synthesis requires hydrocarbons and a significant carbon footprint, as well as significant transportation logistics. Instead of synthesizing ammonia, research into ammonia sources and separation potential brought new process considerations. Ammonia fertilizer salts can be sourced from organic material decay, such as municipal sewage, landfill leachate, and fishery water. These ammonia sources can produce struvite via air stripping ammonium rich feed stock. Anhydrous ammonia was not a viable product of these ammonium-ammonia sources. These ammonia sources also require considerable amounts of feed supply to meet the production demand, it was determined that the local population of the Minnesota River Valley would not be capable of producing a feed supply at a rate that would meet production requirement of 50 metric tons per day. Ammonia salt could be a “green” solution to ammonia fertilizer production, however it was not suitable for this project. It may have potential for other applications.

Acknowledgements

The professors for our senior design class deserve acknowledgement for helping with general questions and encouraging us to explore a menagerie of different options in regard to different design programs and sources. Dr. Ramsey was very helpful in guiding us to look into many options. Dr. Hemmati challenged the group by helping us to think more critically on concepts we were stuck on with multiple hang ups the group had in the design portion of the project. Dr. Kim really helped with teaching valve placement and general PFD design principles through his controls class.

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Appendix

Appendix I

Table 1: Complete Equipment List

Equipment	Name	Quantity
F-101	Dry Air Filter	1
C-101	Pressure Swing Adsorber Compressor	1
V-101A/B	Pressure Swing Adsorber Bed	2
V-102A/B	Pressure Swing Adsorber Bed	2
V-103A/B	Pressure Swing Adsorber	2
V-104	Nitrogen Buffer Tank	1
R-201	Alkaline Electrolyzer	125 stacks
T-201	O2-H2O separator	1
V-201	H2O Storage	1
V-202	O2 Storage	1
E-201	Heat Exchanger	1
E-202	Air cooler	1
P-201 A/B	Electrolyzer feed pump	2
M-301	Mixer	1
C-301	Compressor	1
R-301	Conversion Reactor	1
E-301	Heat Exchanger	1
E-302	Cooler	1
T-301	Separator Column	1
V-301	Storage Tank	1

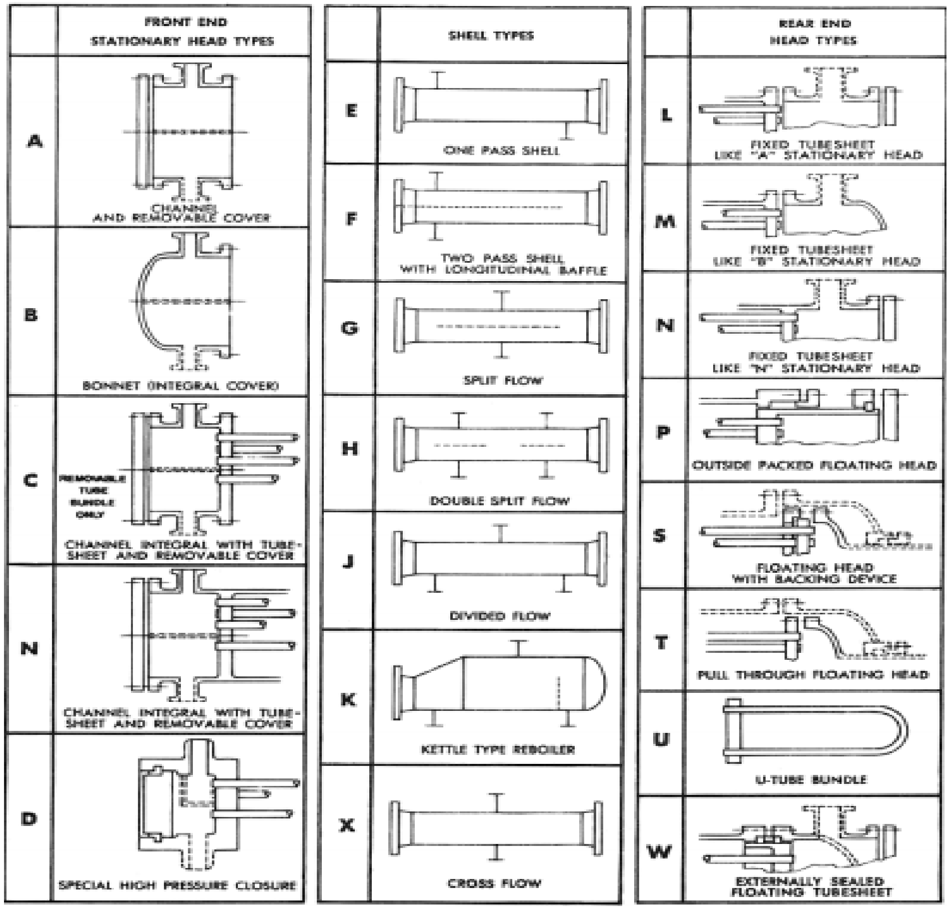


Figure 1: Shell and Tube Heat Exchanger Nomenclature

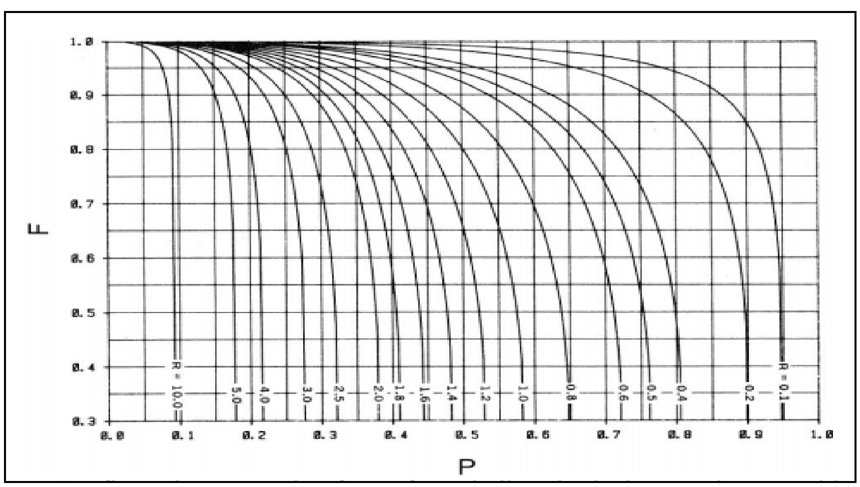


Figure 2: The Correction Factor for LMTD

Appendix II

N_2 SDS

SAFETY DATA SHEET

Nitrogen

Section 1. Identification

GHS product identifier : Nitrogen

Chemical name : nitrogen

Other means of identification : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

Product type : Gas.

Product use : Synthetic/Analytical chemistry.

Synonym : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

SDS # : 001040

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : GASES UNDER PRESSURE - Compressed gas
SIMPLE ASPHYXIANTS

GHS label elements

Hazard pictograms :

Signal word : Warning

Hazard statements : Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statements

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

Prevention : Not applicable.

Response : Not applicable.

Storage : Protect from sunlight. Store in a well-ventilated place.

Disposal : Not applicable.

Supplemental label elements : Keep container tightly closed. Use only with adequate ventilation. Do not enter storage areas and confined spaces unless adequately ventilated.

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

H_2 SDS

SAFETY DATA SHEET

Hydrogen

Section 1. Identification

GHS product identifier	:	Hydrogen
Chemical name	:	hydrogen
Other means of identification	:	Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H2; UN 1049
Product type	:	Gas.
Product use	:	Synthetic/Analytical chemistry.
Synonym	:	Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H2; UN 1049
SDS #	:	001026
Supplier's details	:	Airgas USA, LLC and its affiliates 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
24-hour telephone	:	1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE GASES - Category 1
GASES UNDER PRESSURE - Compressed gas

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : Extremely flammable gas.
May form explosive mixtures with air.
Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.
Burns with invisible flame.

Precautionary statements

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

Prevention : Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

Response : Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.

Storage : Protect from sunlight. Store in a well-ventilated place.

Disposal : Not applicable.

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

NH_3 SDS

SAFETY DATA SHEET

Ammonia

Airgas
an Air Liquide company

Section 1. Identification

GHS product identifier : Ammonia

Chemical name : ammonia

Other means of identification : ammonia; anhydrous ammonia

Product type : Gas.

Product use : Synthetic/Analytical chemistry.

Synonym : ammonia; anhydrous ammonia

SDS # : 001003

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE GASES - Category 2
GASES UNDER PRESSURE - Liquefied gas
ACUTE TOXICITY (inhalation) - Category 4
SKIN CORROSION - Category 1
SERIOUS EYE DAMAGE - Category 1
AQUATIC HAZARD (ACUTE) - Category 1

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : Flammable gas.
May form explosive mixtures with air.
Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.
Harmful if inhaled.
Causes severe skin burns and eye damage.
Very toxic to aquatic life.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Always keep container in upright position. Approach suspected leak area with caution.

Prevention : Wear protective gloves. Wear eye or face protection. Wear protective clothing. Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. Use only outdoors or in a well-ventilated area. Avoid release to the environment. Avoid breathing gas. Wash hands thoroughly after handling.

SAFETY DATA SHEET

Oxygen

Airgas
an Air Liquide company

Section 1. Identification

GHS product identifier	:	Oxygen
Chemical name	:	oxygen
Other means of identification	:	Molecular oxygen; Oxygen molecule; Pure oxygen; O2; UN 1072; Dioxygen; Oxygen USP, Aviator's Breathing Oxygen (ABO)
Product type	:	Gas.
Product use	:	Synthetic/Analytical chemistry.
Synonym	:	Molecular oxygen; Oxygen molecule; Pure oxygen; O2; UN 1072; Dioxygen; Oxygen USP, Aviator's Breathing Oxygen (ABO)
SDS #	:	001043
Supplier's details	:	Airgas USA, LLC and its affiliates 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
24-hour telephone	:	1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status	:	This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Classification of the substance or mixture	:	OXIDIZING GASES - Category 1 GASES UNDER PRESSURE - Compressed gas

GHS label elements

Hazard pictograms :

Signal word	:	Danger
Hazard statements	:	May cause or intensify fire; oxidizer. Contains gas under pressure; may explode if heated.

Precautionary statements

General	:	Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Open valve slowly. Use only with equipment cleaned for Oxygen service.
Prevention	:	Keep away from clothing, incompatible materials and combustible materials. Keep reduction valves, valves and fittings free from oil and grease.
Response	:	In case of fire: Stop leak if safe to do so.
Storage	:	Protect from sunlight. Store in a well-ventilated place.
Disposal	:	Not applicable.
Hazards not otherwise classified	:	None known.

H_2O SDS

Water

Safety Data Sheet

according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

Date of issue: 11/15/2013 Revision date: 06/12/2018 Supersedes: 01/25/2017 Version: 1.3

SECTION 1: Identification

1.1. Identification

Product form	:	Substance
Substance name	:	Water
CAS-No.	:	7732-18-5
Product code	:	LC26750
Formula	:	H2O

1.2. Recommended use and restrictions on use

Use of the substance/mixture	:	For laboratory and manufacturing use only.
Recommended use	:	Laboratory chemicals
Restrictions on use	:	Not for food, drug or household use

1.3. Supplier

LabChem Inc
Jackson's Pointe Commerce Park Building 1000, 1010 Jackson's Pointe Court
Zelienople, PA 16063 - USA
T 412-826-5230 - F 724-473-0647
info@labchem.com - www.labchem.com

1.4. Emergency telephone number

Emergency number	:	CHEMTREC: 1-800-424-9300 or +1-703-741-5970

SECTION 2: Hazard(s) identification

2.1. Classification of the substance or mixture

GHS-US classification

Not classified

2.2. GHS Label elements, including precautionary statements

Not classified as a hazardous chemical.

Other hazards not contributing to the classification	:	None.

2.4. Unknown acute toxicity (GHS US)

Not applicable

SECTION 3: Composition/Information on ingredients

3.1. Substances

Substance type	:	Mono-constituent

Name	Product identifier	%	GHS-US classification
Water (Main constituent)	(CAS-No.) 7732-18-5	100	Not classified

Full text of hazard classes and H-statements : see section 16

3.2. Mixtures

Not applicable

SECTION 4: First-aid measures

4.1. Description of first aid measures

First-aid measures general	:	If you feel unwell, seek medical advice (show the label where possible).
First-aid measures after inhalation	:	Allow victim to breathe fresh air. Allow the victim to rest. Adverse effects not expected from this product.
First-aid measures after skin contact	:	Adverse effects not expected from this product. Take off contaminated clothing.
First-aid measures after eye contact	:	Adverse effects not expected from this product.
First-aid measures after ingestion	:	Do NOT induce vomiting. Adverse effects not expected from this product.

4.2. Most important symptoms and effects (acute and delayed)

Symptoms/effects	:	Not expected to present a significant hazard under anticipated conditions of normal use.

Appendix III

Electrolyzer Material Balance

POLYMATH Report
Explicit Equations

Calculated values of explicit variables

	Variable	Value
1	b	1.
2	c	0.5
3	FH2	50.9715
4	FH2O	0
5	FH2Oo	50.9715
6	FO2	25.48575
7	mH2	102.7585
8	mH2Oo	918.2658
9	mO2	815.544
10	MWH2	2.016
11	MWH2O	18.01528
12	MWO2	32.
13	thetaB	0
14	thetaC	0
15	X	1.

Explicit equations

1	X = 1
2	thetaB = 0
3	thetaC = 0
4	b = 1
5	c = 0.5
6	FH2 = 50.9715
7	FH2Oo = FH2 / ((thetaB + (b*X)))
8	FH2O = FH2Oo * (1-X)
9	FO2 = FH2Oo * (thetaC + (c*X))
10	MWO2 = 32
11	MWH2O = 18.01528
12	mO2 = FO2 * MWO2
13	mH2Oo = FH2Oo * MWH2O
14	MWH2 = 2.016
15	mH2 = FH2 * MWH2

General

number of explicit equations: 15

Ammonia Material Balance

POLYMATH Report
Explicit Equations

Calculated values of explicit variables

	Variable	Value
1	a	1.
2	b	3.
3	c	2.
4	FH2	0
5	FH2o	50.9715
6	FN2	0
7	FN2o	16.9905
8	FNH3	33.981
9	mH2o	102.7585
10	mN2o	475.9039
11	mNH3o	578.7304
12	MWH2	2.016
13	MWN2	28.01
14	MWNH3	17.031
15	thetaB	3.
16	ThetaC	0
17	X	1.

Explicit equations

1	a = 1
2	c = 2
3	X = 1
4	FNH3 = 33.981
5	ThetaC = 0
6	FN2o = FNH3 / (ThetaC + ((c/a)*X))
7	b = 3
8	FN2 = FN2o * (1-X)
9	thetaB = 3
10	FH2 = FN2o * (thetaB - ((b/a)*X))
11	FH2o = thetaB * FN2o
12	MWN2 = 28.01
13	MWH2 = 2.016
14	MWNH3 = 17.031
15	mN2o = FN2o * MWN2
16	mH2o = FH2o * MWH2
17	mNH3o = FNH3 * MWNH3

Appendix IV

Economic Analysis

Electrolyzer	Alkaline	Equations	
C = k1	57231.36	$800/kgd	
W (kg/d) Total	8878.3344		
W(kg/day), one module	71.5392		
nstacks	125		
ncells/stack	20		
Cost	800	$/kgd	
p	0.8		
K(125), 2005	2181264.284	K(N) = sum kn	2005 dollars
CE index, 2005	467.2		
CE index, 2020	592.1		
K(125), Dec' 19	$2,764,397.65		
Replacement Cost	$691,099.41	25% of total purchased Cost	

kn=k1 *nstacks^log2 p	Purchased Cost ($), 2005 dollars	
1	57231.36	14307.84
2	45785.088	11446.272
3	40182.34977	10045.58744
4	36628.0704	9157.0176
5	34089.13524	8522.28381
6	32145.87982	8036.469954
7	30589.5624	7647.3906
8	29302.45632	7325.61408
9	28212.17656	7053.04414
10	27271.30819	6817.827048
11	26447.24894	6611.812234
12	25716.70385	6429.175963
13	25062.50087	6265.625217
14	24471.64992	6117.91248
15	23934.10808	5983.527019
16	23441.96506	5860.491264
17	22988.88931	5747.222327
18	22569.74125	5642.435312
19	22180.29692	5545.074231
20	21817.04655	5454.261639
21	21477.04503	5369.261257
22	21157.79915	5289.449788
23	20857.1814	5214.295349
24	20573.36308	5143.340771
25	20304.76196	5076.19049
26	20050.0007	5012.500174
27	19807.87363	4951.968407
28	19577.31994	4894.329984
29	19357.4018	4839.350451
30	19147.28646	4786.821616
31	18946.2314	4736.557851
32	18753.57204	4688.393011
33	18568.71141	4642.177852
34	18391.11145	4597.777862
35	18220.28569	4555.071423
36	18055.793	4513.94825
37	17897.23221	4474.308051
38	17744.23754	4436.059385
39	17596.47466	4399.118665
40	17453.63724	4363.409311
41	17315.44399	4328.860997
42	17181.63602	4295.409006
43	17051.97465	4262.993662
44	16926.23932	4231.55983
45	16804.2259	4201.056476
46	16685.74512	4171.436279
47	16570.62115	4142.655289
48	16458.69047	4114.672617
49	16349.80067	4087.450167

kn=k1 *nstacks^log2 p	Purchased Cost ($), 2005 dollars	
50	16243.80957	4060.952392
51	16140.58431	4035.146076
52	16040.00056	4010.000139
53	15941.94184	3985.485461
54	15846.2989	3961.574725
55	15752.9691	3938.242276
56	15661.85595	3915.463987
57	15572.8686	3893.21715
58	15485.92144	3871.480361
59	15400.93372	3850.23343
60	15317.82917	3829.457292
61	15236.53571	3809.133926
62	15156.98512	3789.246281
63	15079.11284	3769.77821
64	15002.85764	3750.714409
65	14928.16144	3732.040361
66	14854.96913	3713.742282
67	14783.2283	3695.807076
68	14712.88916	3678.222289
69	14643.90429	3660.976072
70	14576.22855	3644.057138
71	14509.81893	3627.454733
72	14444.6344	3611.1586
73	14380.6358	3595.158951
74	14317.78576	3579.446441
75	14256.04856	3564.012139
76	14195.39003	3548.847508
77	14135.77751	3533.944378
78	14077.17973	3519.294932
79	14019.56672	3504.891681
80	13962.9098	3490.727449
81	13907.18142	3476.795354
82	13852.35519	3463.088797
83	13798.40577	3449.601442
84	13745.30882	3436.327205
85	13693.04096	3423.26024
86	13641.57972	3410.39493
87	13590.90348	3397.72587
88	13540.99146	3385.247864
89	13491.82363	3372.955907
90	13443.38072	3360.845181
91	13395.64418	3348.911044
92	13348.59609	3337.149023
93	13302.21922	3325.554806
94	13256.49692	3314.124231
95	13211.41314	3302.853285
96	13166.95237	3291.738093
97	13123.09966	3280.774914
98	13079.84053	3269.960134

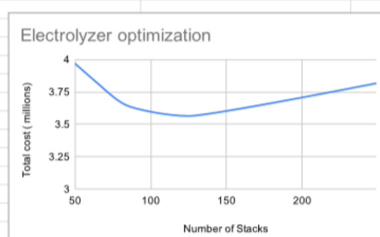
kn=k1 *nstacks^log2 p	Purchased Cost ($), 2005 dollars	
99	13037.16104	3259.290259
100	12995.04766	3248.761914
101	12953.48734	3238.371834
102	12912.46744	3228.116861
103	12871.97576	3217.99394
104	12832.00045	3208.000111
105	12792.53005	3198.132512
106	12753.55348	3188.388369
107	12715.05997	3178.764993
108	12677.03912	3169.25978
109	12639.48082	3159.870206
110	12602.37528	3150.593821
111	12565.713	3141.42825
112	12529.48476	3132.37119
113	12493.68161	3123.420403
114	12458.29488	3114.57372
115	12423.31612	3105.829031
116	12388.73715	3097.184288
117	12354.55002	3088.637504
118	12320.74698	3080.186744
119	12287.32052	3071.83013
120	12254.26334	3063.565834
121	12221.56832	3055.39208
122	12189.22856	3047.307141
123	12157.23734	3039.309334
124	12125.5881	3031.397025
125	12094.27448	3023.568619

N = Total cells	2483							
# of Cells per Stacks	# Electrolyzer Stacks	# Electrolyzer Stacks	W(kg/day), one module	C = k1	Total Purchased Cost, 2005	Total Purchased Cost, 2020	Operating Cost	Total
10	248.3	249	35.7696	28615.68	1.754050672	2.222973893	1.594172219	3.817146112
20	124.15	125	71.5392	57231.36	2.181264284	2.764397651	0.8002705008	3.564668152
30	82.76666667	83	107.3088	85847.04	2.462380214	3.120666363	0.5314090407	3.652075404
40	62.075	63	143.0784	114462.72	2.708453763	3.432524557	0.4033745451	3.835899102
50	49.66	50	178.848	143078.4	2.87898261	3.648642131	0.3201411423	3.968783273

C = k1	28615.68	$800/kgd	Operating Cost	Power	Operation Cost
W(kg/day), one module	35.7696		249	2903.6	1.594172219
Cost	800	$/kgd	125	1457.6	0.8002705008
p	0.8		83	967.9	0.5314090407
K(166), 2005	1247287.247	K(N) = sum kn	63	734.7	0.4033745451
CE index, 2005	467.2		50	583.1	0.3201411423
CE index, December 19	592.1				

Service factor	0.9583333333	
Electricity	0.0654	$/kWh

# of Cells per Stacks	# Electrolyzer Stacks	Total Purchased Cost, 2020	Operating Cost	Total
10	249	$2,222,974	$1,594,172	$3,817,146
20	125	$2,764,398	$800,271	$3,564,668
30	83	$3,120,666	$531,409	$3,652,075
40	63	$3,432,525	$403,375	$3,835,899
50	50	$3,648,642	$320,141	$3,968,783



	Purchased Cost ($), 2005 dollars				kn=k1 *nstacks^log2 p		
kn	249			125	83	63	50
1	28615.68	126	6031.645136	57231.36	85847.04	114462.72	143078.4
2	22892.544	127	6016.314721	45785.088	68677.632	91570.176	114462.72
3	20091.17489	128	6001.143054	40182.34977	60273.52466	80364.69954	100455.8744
4	18314.0352	129	5986.12727	36628.0704	54942.1056	73256.1408	91570.176
5	17044.56762	130	5971.264577	34089.13524	51133.70286	68178.27048	85222.8381
6	16072.93991	131	5956.552254	32145.87982	48218.81973	64291.75963	80364.69954
7	15294.7812	132	5941.98765	30589.5624	45884.3436	61179.1248	76473.906
8	14651.22816	133	5927.56818	29302.45632	43953.68448	58604.91264	73256.1408
9	14106.08828	134	5913.291321	28212.17656	42318.26484	56424.35312	70530.4414
10	13635.6541	135	5899.154615	27271.30819	40906.96229	54542.61639	68178.27048
11	13223.62447	136	5885.155663	26447.24894	39670.87341	52894.49788	66118.12234
12	12858.35193	137	5871.292124	25716.70385	38575.05578	51433.40771	64291.75963
13	12531.25043	138	5857.561715	25062.50087	37593.7513	50125.00174	62656.25217
14	12235.82496	139	5843.962206	24471.64992	36707.47488	48943.29984	61179.1248
15	11967.05404	140	5830.491421	23934.10808	35901.16212	47868.21616	59835.27019
16	11720.98253	141	5817.147235	23441.96506	35162.94758	46883.93011	58604.91264
17	11494.44465	142	5803.927573	22988.88931	34483.33396	45977.77862	57472.22327
18	11284.87062	143	5790.830408	22569.74125	33854.61187	45139.4825	56424.35312
19	11090.14846	144	5777.85376	22180.29692	33270.44539	44360.59385	55450.74231
20	10908.52328	145	5764.995694	21817.04655	32725.56983	43634.09311	54542.61639
21	10738.52251	146	5752.254322	21477.04503	32215.56754	42954.09006	53692.61257
22	10578.89958	147	5739.627794	21157.79915	31736.69873	42315.5983	52894.49788
23	10428.5907	148	5727.114306	20857.1814	31285.77209	41714.36279	52142.95349
24	10286.68154	149	5714.712091	20573.36308	30860.04462	41146.72617	51433.40771
25	10152.38098	150	5702.419423	20304.76196	30457.14294	40609.52392	50761.9049
26	10025.00035	151	5690.234614	20050.0007	30075.00104	40100.00139	50125.00174
27	9903.936813	152	5678.156012	19807.87363	29711.81044	39615.74725	49519.68407
28	9788.659969	153	5666.182003	19577.31994	29365.97991	39154.63987	48943.29984
29	9678.700901	154	5654.311005	19357.4018	29036.1027	38714.80361	48393.50451
30	9573.643231	155	5642.541473	19147.28646	28720.92969	38294.57292	47868.21616
31	9473.115702	156	5630.871892	18946.2314	28419.34711	37892.46281	47365.57851
32	9376.786022	157	5619.300781	18753.57204	28130.35807	37507.14409	46883.93011
33	9284.355704	158	5607.82669	18568.71141	27853.06711	37137.42282	46421.77852
34	9195.555723	159	5596.448199	18391.11145	27586.66717	36782.22289	45977.77862
35	9110.142846	160	5585.163918	18220.28569	27330.42854	36440.57138	45550.71423
36	9027.896499	161	5573.972485	18055.793	27083.6895	36111.586	45139.4825
37	8948.616103	162	5562.872567	17897.23221	26845.84831	35794.46441	44743.08051
38	8872.118769	163	5551.862857	17744.23754	26616.35631	35488.47508	44360.59385
39	8798.237331	164	5540.942076	17596.47466	26394.71199	35192.94932	43991.18665
40	8726.818622	165	5530.108969	17453.63724	26180.45587	34907.27449	43634.09311

41	8657.721993	166	5519.362307	17315.44399	25973.16598	34630.88797	43288.60997
42	8590.818011	167	5508.700887	17181.63602	25772.45403	34363.27205	42954.09006
43	8525.987324	168	5498.123527	17051.97465	25577.96197	34103.9493	42629.93662
44	8463.11966	169	5487.629071	16926.23932	25389.35898	33852.47864	42315.5983
45	8402.112952	170	5477.216384	16804.2259	25206.33886	33608.45181	42010.56476
46	8342.872559	171	5466.884353	16685.74512	25028.61768	33371.49023	41714.36279
47	8285.310577	172	5456.631887	16570.62115	24855.93173	33141.24231	41426.55289
48	8229.345233	173	5446.457917	16458.69047	24688.0357	32917.38093	41146.72617
49	8174.900334	174	5436.361393	16349.80067	24524.701	32699.60134	40874.50167
50	8121.904785	175	5426.341285	16243.80957	24365.71435	32487.61914	40609.52392
51	8070.292153	176	5416.396582	16140.58431	24210.87646	32281.16861	
52	8020.000278	177	5406.526296	16040.00056	24060.00083	32080.00111	
53	7970.970922	178	5396.729451	15941.94184	23912.91277	31883.88369	
54	7923.149451	179	5387.005095	15846.2989	23769.44835	31692.5978	
55	7876.484552	180	5377.352289	15752.9691	23629.45365	31505.93821	
56	7830.927975	181	5367.770116	15661.85595	23492.78392	31323.7119	
57	7786.434299	182	5358.257671	15572.8686	23359.3029	31145.7372	
58	7742.960721	183	5348.814068	15485.92144	23228.88216	30971.84288	
59	7700.46686	184	5339.438438	15400.93372	23101.40058	30801.86744	
60	7658.914585	185	5330.129924	15317.82917	22976.74375	30635.65834	
61	7618.267853	186	5320.887689	15236.53571	22854.80356	30473.07141	
62	7578.492562	187	5311.710908	15156.98512	22735.47769	30313.97025	
63	7539.55642	188	5302.59877	15079.11284	22618.66926	30158.22568	
64	7501.428818	189	5293.55048	15002.85764	22504.28645		
65	7464.080721	190	5284.565256	14928.16144	22392.24216		
66	7427.484563	191	5275.642331	14854.96913	22282.45369		
67	7391.614151	192	5266.780949	14783.2283	22174.84245		
68	7356.444578	193	5257.980369	14712.88916	22069.33374		
69	7321.952144	194	5249.239863	14643.90429	21965.85643		
70	7288.114277	195	5240.558712	14576.22855	21864.34283		
71	7254.909466	196	5231.936214	14509.81893	21764.7284		
72	7222.3172	197	5223.371675	14444.6344	21666.9516		
73	7190.317902	198	5214.864414	14380.6358	21570.95371		
74	7158.892882	199	5206.413763	14317.78576	21476.67865		
75	7128.024279	200	5198.019062	14256.04856	21384.07284		
76	7097.695016	201	5189.679665	14195.39003	21293.08505		
77	7067.888757	202	5181.394934	14135.77751	21203.66627		
78	7038.589865	203	5173.164244	14077.17973	21115.76959		
79	7009.783362	204	5164.986978	14019.56672	21029.35009		
80	6981.454898	205	5156.86253	13962.9098	20944.36469		
81	6953.590709	206	5148.790303	13907.18142	20860.77213		
82	6926.177594	207	5140.769712	13852.35519	20778.53278		

83	6899.202884	208	5132.800178	13798.40577	20697.60865		
84	6872.654409	209	5124.881134	13745.30882			
85	6846.52048	210	5117.01202	13693.04096			
86	6820.789859	211	5109.192286	13641.57972			
87	6795.451741	212	5101.42139	13590.90348			
88	6770.495728	213	5093.698799	13540.99146			
89	6745.911814	214	5086.023989	13491.82363			
90	6721.690362	215	5078.396441	13443.38072			
91	6697.822088	216	5070.815648	13395.64418			
92	6674.298047	217	5063.281109	13348.59609			
93	6651.109612	218	5055.792329	13302.21922			
94	6628.248462	219	5048.348823	13256.49692			
95	6605.70657	220	5040.950113	13211.41314			
96	6583.476186	221	5033.595727	13166.95237			
97	6561.549828	222	5026.2852	13123.09966			
98	6539.920267	223	5019.018076	13079.84053			
99	6518.580518	224	5011.793904	13037.16104			
100	6497.523828	225	5004.612239	12995.04766			
101	6476.743668	226	4997.472646	12953.48734			
102	6456.233722	227	4990.374691	12912.46744			
103	6435.987879	228	4983.317952	12871.97576			
104	6416.000223	229	4976.302008	12832.00045			
105	6396.265025	230	4969.326449	12792.53005			
106	6376.776738	231	4962.390867	12753.55348			
107	6357.529986	232	4955.494861	12715.05997			
108	6338.519561	233	4948.638038	12677.03912			
109	6319.740411	234	4941.820006	12639.48082			
110	6301.187641	235	4935.040383	12602.37528			
111	6282.8565	236	4928.29879	12565.713			
112	6264.74238	237	4921.594854	12529.48476			
113	6246.840807	238	4914.928207	12493.68161			
114	6229.147439	239	4908.298487	12458.29488			
115	6211.658061	240	4901.705334	12423.31612			
116	6194.368577	241	4895.148398	12388.73715			
117	6177.275008	242	4888.627329	12354.55002			
118	6160.373488	243	4882.141784	12320.74698			
119	6143.660259	244	4875.691426	12287.32052			
120	6127.131668	245	4869.275919	12254.26334			
121	6110.784161	246	4862.894935	12221.56832			
122	6094.614282	247	4856.548149	12189.22856			
123	6078.618669	248	4850.23524	12157.23734			
124	6062.79405	249	4843.955891	12125.5881			

PSA		Equations
Material	CS	
CoP	5,468.14	Log10CoP = K1 + K2*Log10 (A) + K3* (Log10 (A))2
Volume (m3)	3.03	A x h (add height for bottom and top caps)
K1	3.50	
K2	0.45	
K3	0.11	
FP	1.11	FP, tower = ((((P+1)*D)/(2*S*E - 1.2*(P+1))) + CA)/tmin
P (barg)	5.00	
Diameter, D (m)	1.09	
Material ID	20.00	carbon steel
FBM	8.32	
CP, 2001	50,520.24	CP, 2001 = CoP * FP * FBM
CP, Mid-year 2020		CP, Mid-year 2020 = CP, 2001 * (592.1/397)
CBM, 2001	45,473.13	CBM,2001 = CoP *FBM
CBM, Mid-year 2020	67,820.25	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)
kn	43,404.96	kn=k1 *n^log2 p
n = # of module	4.00	
p	0.80	
K()		K(N) = sum kn

number feed splits	3
Area	0.9278
diameter	1.086
bed height	3.2606
total V	3.02518468

number of tanks = number of splits x 2

Functioning Version		
n	kn	K()
1	67820.25133	67,820.25
2	54256.20107	122,076.45
3	47616.84958	169,693.30
4	43404.96085	213,098.26
5	40396.27435	253,494.54
6	38093.47967	291,588.02
7	36249.2139	327,837.23
8	34723.96868	362,561.20
9	33431.96641	395,993.17
10	32317.01948	428,310.19
11	31340.49357	459,650.68
12	30474.78373	490,125.46
13	29699.54074	519,825.00
14	28999.37112	548,824.37
15	28362.3738	577,186.75

PSA		Equations
	L/D = 3	
Material	SS	
CoP	78,344.41	Log10CoP = K1 + K2*Log10 (A) + K3* (Log10 (A))2
Volume (m3)	119.94	A x h (add height for bottom and top caps)
K1	3.50	
K2	0.45	
K3	0.11	
FP	1.94	FP, tower = ((((P+1)*D)/(2*S*E - 1.2*(P+1))) + CA)/tmin
P (barg)	4.99	
Diameter, D (m)	3.09	
Material ID	20.00	carbon steel
FBM	12.87	
CP, 2001	1,960,582.56	CP, 2001 = CoP * FP * FBM
CP, Mid-year 2020	2,924,082.96	CP, Mid-year 2020 = CP, 2001 * (592.1/397)
CBM, 2001	1,008,152.63	CBM,2001 = CoP *(B1+B2*Fm*Fp)
CBM, Mid-year 2020	1,503,594.90	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)

*Make sure my bar to barg conversion is accurate

Useful values				
Op. Temperature	280	Deg C		
Op. Pressure	6	bar	4.98675	barg
atm. Pressure	1.01325	bar		

Tank Sizing (model: cylinder w/ hemispherical caps)		
L/D ratio =	3	4.5
Volume (m3)	119.94	119.94
Diameter (m)	3.466353389	3.091907541
CS Area (m2)	9.437034739	7.50832181
Height, L (m)	10.39906017	13.91358394
CBM 2020	713,674.45	676,466.78

A	B	C	D
Mixer	impeller	separator	
Material	CS	CS	
CoP	21921.05786	1933896.874	Log10CoP = K1 + K2*Log10 (A) + K3* (Log10 (A))2
Power (kW)	5	2625	
K1	3.8511	3.4974	
K2	0.7009	0.4485	
K3	-0.0003	0.1074	
FP	1	1	Log10FP = C1 + C2*Log10 (P) + C3* (Log10 (P))2
P (barg)	60	1.01325	
C1	0	0	
C2	0	0	
C3	0	0	
Material ID			
FBM	1.38	1	
CP, 2001	30251.05984	1933896.874	CP, 2001 = CoP * FP * FBM
CP, Mid-year 2020	45117.51268	2884282.971	CP, Mid-year 2020 = CP, 2001 * (592.1/397)
CBM, 2001	30251.05984	1933896.874	CBM,2001 = CoP *FBM
CBM, Mid-year 2020	45117.51268	2884282.971	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)

Reactor	Jacketed nonagitated		sim 2	Equations
Material	CS	CS	SS	
CoP	10244.95014	10244.95014	10244.95014	Log10CoP = K1 + K2*Log10 (A) + K3* (Log10 (A))2
Volume (m3)	8.14	8.14	8.14	Change it
K1	3.3496	3.3496	3.3496	
K2	0.7235	0.7235	0.7235	
K3	0.0025	0.0025	0.0025	
FP	0.8586533093	11.83835634	11.83835634	FP, tower = ((((P+1)*D)/(2*S*E - 1.2*(P+1))) + CA)/tmin
P (barg)	1.0135	60	60	Change it
Diameter, D (m)	1.905	1.905	1.905	
FBM	4	4	4	
CP, 2001	35187.44135	485133.4816	485133.4816	CP, 2001 = CoP * FP * FBM
CP, Mid-year 2020	52479.80862	723545.4269	723545.4269	CP, Mid-year 2020 = CP, 2001 * (592.1/397)
CBM, 2001	40979.80054	40979.80054	40979.80054	CBM,2001 = CoP *FBM
CBM, Mid-year 2020	61118.74031	61118.74031	61118.74031	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)
kn	3.3496	3.3496	3.3496	kn=k1 *n^log2 p
n = # of module	1	1	1	
p	0.8	0.8	0.8	
K()				K(N) = sum kn
	both of these reactors are in terms of original sim			

A	B	C
	Separator 1	Equation
Type	Vertical	
Diameter, D (m)	1.524	
L (m)	3.048	
Volume (m3) , V	5.56	
Area (m2), A	1.824146925	A = pi*D2/4
Design Pressure, P (barg)	16.43381136	
Material of column	CS	
Tower		
K1	3.4974	
K2	0.4485	
K3	0.1074	
CoP	7,783.73	Log10CoP = K1 + K2*Log10 (V) + K3* (Log10 (V))2
FP, tower	3.01	FP, tower = ((((P+1)*D)/(2*S*E - 1.2*(P+1))) + CA)/tmin
Material ID	18	
FM	1	
CP, 2001	23,442.16	CP, 2001 = CoP * FP, tower * FM
CP, Mid-year 2020	34,962.47	CP, Mid-year 2020 = CP, 2001 * (592.1/397)
B1	2.25	
B2	1.82	
CBM, 2001	181,237.64	CBM, 2001 = CoP *(B1 + B2*FM*FP)
CBM, Mid-year 2020	$270,304.30	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)

A	B	C	D	E
Compressor	Electrolyzer	ammonia	psa	Equations
Material	SS	SS	SS	
CoP	126,524.10	289,541.15	1,641.87	Log10CoP = K1 + K2*Log10 (A) + K3* (Log10 (A))2
Power (kW)	366.00	1,048.00	5.24	
K1	2.29	2.29	2.29	
K2	1.36	1.36	1.36	
K3	-0.10	-0.10	-0.10	
FP	1.00	1.00	1.00	Log10FP = C1 + C2*Log10 (P) + C3* (Log10 (P))2
P (barg)	219.00	60.00	5.00	
C1	0.00	0.00	0.00	
C2	0.00	0.00	0.00	
C3	0.00	0.00	0.00	
Material ID	2.00	2.00	2.00	
FBM	5.80	5.87	5.80	
CP, 2001	733,839.80	1,699,606.53	9,522.84	CP, 2001 = CoP * FP * FBM
CP, Mid-year 2020	1,094,474.92	2,534,853.97	14,202.70	CP, Mid-year 2020 = CP, 2001 * (592.1/397)
CBM, 2001	733,839.80	1,699,606.53	9,522.84	CBM,2001 = CoP *FBM
CBM, Mid-year 2020	$1,094,474.92	2,534,853.97	14,202.70	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)

Pump	Electrolyzer (2 pumps)	Equation
Voulumetric Flowarate, Q	575.00000	
Pressure gain, dP (psi)	194.9520	
Hydraulic HP	65.36292	Hydraulic HP =(Q*dP)/1715
Pump efficiency	0.80000	
Brake HP	81.70364	Brake HP = Hydraulic HP/Pump efficiency
Motor efficiency	0.90000	
Purchased HP	90.78183	Purchased HP = Brake HP/Motor efficiency
Power (kWatt)	67.69601	Purchased HP * 0.7457
Power (kWatt)	68.00000	
Design Pressure (barg)	17.00129	
Material	CS	
K1	3.38920	
K2	0.05360	
K3	0.15380	
CoP	10090.12515	Log10CoP = K1 + K2*Log10 (A) + K3* (Log10 (A))2
C1	-0.39350	
C2	0.39570	
C3	-0.00226	
FP	1.25021	Log10FP = C1 + C2*Log10 (P) + C3* (Log10 (P))2
Material ID	38.00000	
FM	1.55000	
CP, 2001	19612.52264	CP, 2001 = CoP * FP * FM
CP, Mid-year 2020	$29,250.82	CP, Mid-year 2020 = CP, 2001 * (592.1/397)
B1	1.89000	
B2	1.35000	
CBM, 2001	45547.24210	CBM, 2001 = CoP *(B1 + B2*FM*FP)
CBM, Mid-year 2020	$67,930.79	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)

Total (2 pumps), electroly	$135,861.57

Psuction = P Storage Tank +Pelevation - Pfric -P valves
P discharge = P Heat Exchanger + P elev + Pfric + Pvalve + P Control valve
Head, H = dp*2.31/SG

maximum flowrates were decided based on GPSA handbook

Head, ft		10% factor	Operating flowrate (gpm)	max flowrate (gpm)
Pump1 (Total 82)	453.515716	498.8650876	14.55484229	575
Pump2				

Pressure drop	P Suction	P Discharge	dP	Unit
Pump 1	1.5667	196.5186667	194.9520	psig
Pump 2				

Friction	Suction	quantity	Discharge	unit
Piping	0.5		3	psi
Valve	0.1	1	0.1	psi
Orifice			1.2	psi
Filter			15	psi
Check Valve		1	1	psi
Control Valve		1	10	psi

pressure drop data was taken from the GPSA handbook

Height		unit
Storage tank	60.0000	in
Heat Exchanger	240	in

Pressure (psia)	Electrolyzer
Storage tank	14.7
Heat Exchanger	188.552

	Water	Unit
Density	0.0361	lb/in3
gravity	32.2000	ft/s2
SG	0.993	

Heat Exchanger	1-Electrolyzer	2-Electrolyzer	cooler	Ammonia 2.0	Equation
Type	Floating head	Floating head			
Area, A (m2)	6.127565397	4.375180785	54.34806686	17.93877496	Q = U * A * deltaTlm or Q = m Cp dT
Shell Pressure, P (barg)	14	14	60	60	
Shell material	CS	SS	SS	SS	
Tube Pressure, P (barg)	13.98648649	13.98648649	60	60	Boiler Feed Water
Tube material	Cu	SS	CS	SS	need to verify
Heat, Q (W)	88408.79469	405000	17610000	1933611.111	Provided by Hysys
MTD = F*delta Tlm	15.73396901	148.4641948	256.5178636	85.33333333	delta C = delta K, F*LMTD, f(P,R)
U (W/m2K)	916.9997649	623.501199	1263.157895	1263.157895	
K1	4.8306	4.8306	4.0336	4.8306	kettle reboiler
K2	-0.8509	-0.8509	0.2341	-0.8509	
K3	0.3187	0.3187	0.0497	0.3187	
CoP	22815.71345	26068.89619	38854.9659	18396.82832	$\log_{10} CoP = K1 + K2 \cdot \log_{10}(A) + K3 \cdot (\log_{10}(A))^2$
C1	0.038881	0.038881	0	0.038881	
C2	-0.011272	-0.011272	0	-0.011272	
C3	0.08183	0.08183	0	0.08183	
FP	1.359735725	1.359735725	1	1.894826992	$\log_{10} FP = C1 + C2 \cdot \log_{10}(P) + C3 \cdot (\log_{10}(P))^2$
Material ID	2	2	10	2	depend on the materials
FM	1.4	2.67	1	1.4	
CP, 2001	43432.67693	94642.98125	38854.9659	48802.32961	CP, 2001 = CoP * FP * FM
CP, Mid-year 2020	64777.04789	141153.9275	57949.68591	72785.53995	CP, Mid-year 2020 = CP, 2001 * (592.1/397)
B1	1.63	1.63	0.96	1.63	
B2	1.66	1.66	1.21	1.66	
CBM, 2001	109287.8566	199599.6497	84315.27599	110998.6973	CBM, 2001 = CoP *(B1 + B2*FM*FP)
CBM, Mid-year 2020	$162,995.82	$297,690.06	$125,750.82	$165,547.43	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)

Temperature (oC)	1-Electrolyzer			
T tube in	40	7	707.4	618.7
T tube out	35	51.7	-50	535
T shell in	7	498.5	-97.6	623.7
T shell out	30	51.7	-50	707.4
P = (T tube out - T tube in) / (T shell in - T tube out)	0.1785714286	0.1000447628	15.91176471	1
R = (T shell in - T shell out)/ (T tube out - T tube in)	4.6	9.995525727	0.0628465804	1
F	0.9	0.85	1	1
LMTD = ((Thi - Tco)-(Tho-Tci))/ln((Thi-Tco)/(Tho-Tci))	17.48218779	174.6637586	256.5178636	85.33333333

Material properties	
Cp,water (J/g K)	4.186
Cp,O2 (J/g K)	0.918
mh2o = Q/cp*dT (kg/hr)	7792.032887

Electrolyzer - HEX1			
U	shell/water	tube/water-O2	U=((1/ho)+Rfi+Rfo+(1/hi))^(-1)
do / di (m)	tube d ratio = 1		tube diameter, in, inside diameter based on 12gauge tubing wall thickness, Di=Do-2*wall thickness, Do based on chart with F=1
ho / hi	6500	1500	heat transfer coef, W/m2K, Sensible Heat Transfer for Water, Condensing heat transfer Light Organics, liquid viscosity < 0.5*10^3
Rfo / Rfi	0.00015	0.00012	Fouling Resistance, m^2K/W
kw	45.8		thermal cond. wall material,W/m/K, basedon CS at 100C, pg802 Turton
U	shell/Ammonia/H2/N	tube/H2-N2 MI	U=((1/ho)+Rfi+Rfo+(1/hi))^(-1)
do / di (m)	tube d ratio = 1		tube diameter, in, inside diameter based on 12gauge tubing wall thickness, Di=Do-2*wall thickness, Do based on chart with F=1
ho / hi	15000	2000	heat transfer coef, W/m2K, Sensible Heat Transfer for ammonia, Condensing heat transfer Light Organics, liquid viscosity < 0.5*10^3
Rfo / Rfi	0.000075	0.00015	Fouling Resistance, m^2K/W
kw			thermal cond. wall material,W/m/K, basedon CS at 100C, pg802 Turton
Electrolyzer - HEX2			
U	shell/O2	tube/ Cooling w	U=((1/ho)+Rfi+Rfo+(1/hi))^(-1)
do / di (m)	tube d ratio = 1		tube diameter, in, inside diameter based on 12gauge tubing wall thickness, Di=Do-2*wall thickness, Do based on chart with F=1
ho / hi	800	6500	heat transfer coef, W/m2K, Sensible Heat Transfer for Water, Condensing heat transfer Light Organics, liquid viscosity < 0.5*10^3
Rfo / Rfi	0.00005	0.00015	Fouling Resistance, m^2K/W
kw			thermal cond. wall material,W/m/K, basedon CS at 100C, pg802 Turton

O2 Tanks		H2O storage	Equation	O2 stoage		
Type	Horizontal	Vertical		Volumetric Flowrate (m3/h)	2.588	
Diameter, D (m)	0.6041097227	0.5142869169		t(h)	1	
L (m)	1.208219445	1.542860751		Volume at 50% full	2.588	
Volume (m3) , V	5.176	6.6096			5.176	
Volume (m3) , V	5.6936	7.27056	10% oversized	L/D	2	
Area (m2), A	0.2866299264	137.2461681		Volume of cylinder		pi*r^2 * h
Design Pressure, P (barg)	219	3.448275862		D	0.6041097227	
Material of column	CS	CS				
Cylinder				H2O storage		
K1	3.5565	3.4974		L/D	3	
K2	0.3776	0.4485		density (kg/m3)	1000	
K3	0.0905	0.1074		Ammount(kg/h)	3304.8	
CoP	7,823.02	9,194.67	Log10CoP = K1 + K2*Log10 (V) + K3* (Log10 (V))2	Volumeetric flowrate (m3/hr	3.3048	
FP, tower	15.19	0.71	FP, tower = ((((P+1)*D)/(2*S*E - 1.2*(P+1))) + CA)/tmin	t(h)	1	
Material ID	18	18		Volume (m3)	3.3048	
FM	1	1			6.6096	
CP, 2001	118,837.37	6,567.53	CP, 2001 = CoP * FP, tower * FM	D(m)	0.5142869169	
CP, Mid-year 2020	177,238.31	9,795.05	CP, Mid-year 2020 = CP, 2001 * (592.1/397)			
B1	2.25	2.25				
B2	1.82	1.82				
CBM, 2001	233,885.81	32,640.91	CBM, 2001 = CoP *(B1 + B2*FM*FP)			
CBM, Mid-year 2020	$348,825.66	$48,681.83	CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)			

Nh3 Tanks		H2O storage	Equation	NH3 stoage		
Type	Vertical	Vertical		density (kg/m3)	692.8	
Diameter, D (m)	17.83858591			amount (kg)	52944	
L (m)	35.67717182			L/D	2	
Volume (m3) , V	84.06235566			Volume of cylinder		pi*r^2 * h
Volume (m3) , V	4			r = (volume/(pi*(2/2)))^1/3	8.919292954	
Area (m2), A	249.9255922		A = pi*D2/4			
Design Pressure, P (barg)	60			H2O storage		
Material of column	Al			L/D	3	
Cylinder						
K1	3.4974					
K2	0.4485					
K3	0.1074					
CoP	6,402.56		Log10CoP = K1 + K2*Log10 (V) + K3* (Log10 (V))2			
FP, tower	106.67		FP, tower = ((((P+1)*D)/(2*S*E - 1.2*(P+1))) + CA)/tmin			
Material ID	20					
FM	3.1					
CP, 2001	2,117,246.91		CP, 2001 = CoP * FP, tower * FM			
CP, Mid-year 2020	3,157,737.77		CP, Mid-year 2020 = CP, 2001 * (592.1/397)			
B1	2.25					
B2	1.82					
CBM, 2001	3,867,795.13		CBM, 2001 = CoP *(B1 + B2*FM*FP)			
CBM, Mid-year 2020	5,768,568.01		CBM, Mid-year 2020 = CBM, 2001 * (592.1/397)			

MACRS Depreciation	
Year	20 year
1	0.0375
2	0.07219
3	0.06677
4	0.06177
5	0.05713
6	0.05285
7	0.04888
8	0.04522
9	0.04462
10	0.04461
11	0.04462
12	0.04461
13	0.04462
14	0.04461
15	0.04462
16	0.04461
17	0.04462
18	0.04461
19	0.04462
20	0.04461
21	0.02231

Electrolyzer Depreciation	
year	2,764,397.65
1	103,664.91
2	199,561.87
3	184,578.83
4	170,756.84
5	157,930.04
6	146,098.42
7	135,123.76
Total Depreciation	1,097,714.66
Writeoff	1,666,682.99
Replacement cost	691,099.41
8	25,916.23
9	49,890.47
10	46,144.71
11	42,689.21
12	39,482.51
13	36,524.60
14	33,780.94
Total Depreciation	274,428.67
Writeoff	416,670.75
Replacement cost	691,099.41
15	25916.22798
16	49890.4666
17	46144.70779
18	42689.21072
19	39482.50945
20	36524.60396
21	33780.93929
Total Depreciation	274,428.67
Writeoff	416,670.75

PSA Depreciation	
year	291,588.02
1	10,934.55
2	21,049.74
3	19,469.33
4	18,011.39
5	16,658.42
6	15,410.43
7	14,252.82
8	13,185.61
9	13,010.66
10	13,007.74
Total Depreciation	154,990.69
Writeoff	136,597.32
Replacement Cost	291,588.02
11	10,934.55
12	21,049.74
13	19,469.33
14	18,011.39
15	16,658.42
16	15,410.43
17	14,252.82
18	13,185.61
19	13,010.66
20	13,007.74
21	13,010.66
Total Depreciation	168,001.35
Writeoff	123,586.67

PSA Buffer Tank	
year	1,503,594.90
1	56,384.81
2	108,544.52
3	100,395.03
4	92,877.06
5	85,900.38
6	79,464.99
7	73,495.72
8	67,992.56
9	67,090.40
10	67,075.37
11	67,090.40
12	67,075.37
13	67,090.40
14	67,075.37
15	67,090.40
16	67,075.37
17	67,090.40
18	67,075.37
19	67,090.40
20	67,075.37
21	33,545.20
total depreciation	1,503,594.90
Writeoff	0.00

Reactor Depreciation		
year	61,118.74	61,118.74
1	2,291.95	2,291.95
2	4,412.16	4,412.16
3	4,080.90	4,080.90
4	3,775.30	3,775.30
5	3,491.71	3,491.71
6	3,230.13	3,230.13
7	2,987.48	2,987.48
8	2,763.79	2,763.79
9	2,727.12	2,727.12
10	2,726.51	2,726.51
11	2,727.12	2,727.12
12	2,726.51	2,726.51
13	2,727.12	2,727.12
14	2,726.51	2,726.51
15	2,727.12	2,727.12
16	2,726.51	2,726.51
17	2,727.12	2,727.12
18	2,726.51	2,726.51
19	2,727.12	2,727.12
20	2,726.51	2,726.51
21	1,363.56	1,363.56
Total Depreciation	61,118.74	61,118.74
Writeoff	0.00	0.00

Compressor Depreciation			
	PSA	Ammonia	Electrolyzer
year	14,202.70	2,534,853.97	1,094,474.92
1	532.60	95,057.02	41,042.81
2	1,025.29	182,991.11	79,010.14
3	948.31	169,252.20	73,078.09
4	877.30	156,577.93	67,605.72
5	811.40	144,816.21	62,527.35
6	750.61	133,967.03	57,843.00
7	694.23	123,903.66	53,497.93
8	642.25	114,626.10	49,492.16
9	633.72	113,105.18	48,835.47
10	633.58	113,079.84	48,824.53
11	633.72	113,105.18	48,835.47
12	633.58	113,079.84	48,824.53
13	633.72	113,105.18	48,835.47
14	633.58	113,079.84	48,824.53
15	633.72	113,105.18	48,835.47
16	633.58	113,079.84	48,824.53
17	633.72	113,105.18	48,835.47
18	633.58	113,079.84	48,824.53
19	633.72	113,105.18	48,835.47
20	633.58	113,079.84	48,824.53
21	316.86	56,552.59	24,417.74
Total Depreciation	14,202.70	2,534,853.97	1,094,474.92
Writeoff	0.00	0.00	0.00

Pumps Depreciation	
	Electrolyzer
year	$135,861.57
1	5,094.81
2	9,807.85
3	9,071.48
4	8,392.17
5	7,761.77
6	7,180.28
7	6,640.91
8	6,143.66
9	6,062.14
10	6,060.78
11	6,062.14
12	6,060.78
13	6,062.14
14	6,060.78
15	6,062.14
16	6,060.78
17	6,062.14
18	6,060.78
19	6,062.14
20	6,060.78
21	3,031.07
Total Depreciation	135,861.57
Writeoff	0.00

Heat Exchangers Depreciation			
	E-201	E-202	Ammonia 1
year	162,995.82	297,690.06	165,547.43
1	6,112.34	11,163.38	6,208.03
2	11,766.67	21,490.25	11,950.87
3	10,883.23	19,876.77	11,053.60
4	10,068.25	18,388.31	10,225.86
5	9,311.95	17,007.03	9,457.72
6	8,614.33	15,732.92	8,749.18
7	7,967.24	14,551.09	8,091.96
8	7,370.67	13,461.54	7,486.05
9	7,272.87	13,282.93	7,386.73
10	7,271.24	13,279.95	7,385.07
11	7,272.87	13,282.93	7,386.73
12	7,271.24	13,279.95	7,385.07
13	7,272.87	13,282.93	7,386.73
14	7,271.24	13,279.95	7,385.07
15	7,272.87	13,282.93	7,386.73
16	7,271.24	13,279.95	7,385.07
17	7,272.87	13,282.93	7,386.73
18	7,271.24	13,279.95	7,385.07
19	7,272.87	13,282.93	7,386.73
20	7,271.24	13,279.95	7,385.07
21	3,636.44	6,641.47	3,693.36
Total Depreciation	162,995.82	297,690.06	165,547.43
Writeoff	0.00	0.00	0.00

Ammonia 2		Separator Depreciation			Filter
			Electrolyzer	Ammonia	
125,750.82		year	$270,304.30	2,884,282.97	636.00
4,715.66		1	10,136.41	108,160.61	23.85
9,077.95		2	19,513.27	208,216.39	45.91
8,396.38		3	18,048.22	192,583.57	42.47
7,767.63		4	16,696.70	178,162.16	39.29
7,184.14		5	15,442.48	164,779.09	36.33
6,645.93		6	14,285.58	152,434.36	33.61
6,146.70		7	13,212.47	140,983.75	31.09
5,686.45		8	12,223.16	130,427.28	28.76
5,611.00		9	12,060.98	128,696.71	28.38
5,609.74		10	12,058.27	128,667.86	28.37
5,611.00		11	12,060.98	128,696.71	28.38
5,609.74		12	12,058.27	128,667.86	28.37
5,611.00		13	12,060.98	128,696.71	28.38
5,609.74		14	12,058.27	128,667.86	28.37
5,611.00		15	12,060.98	128,696.71	28.38
5,609.74		16	12,058.27	128,667.86	28.37
5,611.00		17	12,060.98	128,696.71	28.38
5,609.74		18	12,058.27	128,667.86	28.37
5,611.00		19	12,060.98	128,696.71	28.38
5,609.74		20	12,058.27	128,667.86	28.37
2,805.50		21	6,030.49	64,348.35	14.19
125,750.82		Total Depreciatio	270,304.30	2,884,282.97	636.00
0.00		Writeoff	0.00	0.00	0.00

Storage Vessel			
	H2O	Ammonia	O2
year	$48,681.83	$5,768,568.01	$348,825.66
1	1,825.57	216,321.30	13,080.96
2	3,514.34	416,432.92	25,181.72
3	3,250.49	385,167.29	23,291.09
4	3,007.08	356,324.45	21,546.96
5	2,781.19	329,558.29	19,928.41
6	2,572.83	304,868.82	18,435.44
7	2,379.57	281,967.60	17,050.60
8	2,201.39	260,854.65	15,773.90
9	2,172.18	257,393.50	15,564.60
10	2,171.70	257,335.82	15,561.11
11	2,172.18	257,393.50	15,564.60
12	2,171.70	257,335.82	15,561.11
13	2,172.18	257,393.50	15,564.60
14	2,171.70	257,335.82	15,561.11
15	2,172.18	257,393.50	15,564.60
16	2,171.70	257,335.82	15,561.11
17	2,172.18	257,393.50	15,564.60
18	2,171.70	257,335.82	15,561.11
19	2,172.18	257,393.50	15,564.60
20	2,171.70	257,335.82	15,561.11
21	1,086.09	128,696.75	7,782.30
Total Depreciatio	48,681.83	5,768,568.01	348,825.66
Writeoff	0.00	0.00	0.00

Project Title: Ammonia Production
Corporate financial situation: Stand alone
Minimum rate of return, i* = 0.08 or 8%

Sales Price in $/ ton of NH3 according to https://www.ams.usda.gov/mnreports/gx_gr210.txt
503.62 $/ton NH3 = 28181 $/day = 8813830.328 $/yr 176276606.6 $ after 20 years (not including depreciation)
40 $/ton O2 2824.32 $/day 987920.2
555,472,418

1=$1

End of Year	0	1	2	3	4	5	6	7	8	9	10
Production tonnes Anhydrous Ammonia	0	55	55	55	55	55	55	55	55	55	55
x Sales Price, $/metric ton	0	553.982	553.982	553.982	553.982	553.982	553.982	553.982	553.982	553.982	553.982
Production tonnes Oxygen (O2)	0	71	71	71	71	71	71	71	71	71	71
Sales Price $/metric ton	0	40	40	40	40	40	40	40	40	40	40
Sales Revenues	0	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505
(+) Salvage Value	0	0	0	0	0	0	0	0	0	0	0
(-) Royalties	0	0	0	0	0	0	0	0	0	0	0
Net Revenues	0	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505
(-) Other Op Costs	0	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)
(-) Depreciation	0	(1,512,823)	(1,214,257)	(1,123,329)	(1,038,947)	(961,113)	(888,915)	(723,266)	(737,988)	(734,088)	(728,710)
(-) Amortization	0	0	0	0	0	0	0	0	0	0	0
(-) Depletion	0	0	0	0	0	0	0	0	0	0	0
(-) Loss Forward	0	0	0	0	0	0	0	0	0	0	0
(-) Writeoff	0	0	0	0	0	0	0	0	(1,666,683)	0	0
Taxable Income	0	(12,563,147)	(12,464,580)	(12,373,652)	(12,289,271)	(12,211,436)	(12,139,239)	(11,973,589)	(15,654,994)	(11,984,411)	(11,979,034)
(-) Tax @ 25%	0	(3,140,787)	(3,116,145)	(3,093,413)	(3,072,318)	(3,052,859)	(3,034,810)	(2,993,397)	(3,413,748)	(2,996,103)	(2,994,758)
Net Income	0	(15,703,933)	(15,580,726)	(15,467,065)	(15,361,588)	(15,264,295)	(15,174,049)	(14,966,987)	(17,068,742)	(14,980,514)	(14,973,792)
(+) Depreciation	0	1,512,823	1,214,257	1,123,329	1,038,947	961,113	888,915	723,266	737,988	734,088	728,710
(+) Amortization	0	0	0	0	0	0	0	0	0	0	0
(+) Depletion	0	0	0	0	0	0	0	0	0	0	0
(+) Loss Forward	0	0	0	0	0	0	0	0	0	0	0
(+) Writeoff	0	0	0	0	0	0	0	0	1,666,683	0	0
(-) Working Capital	0	0	0	0	0	0	0	0	0	0	0
(-) Fixed Capital	(18,472,739)	0	0	0	0	0	0	0	(891,099)	0	0
Cash Flow	(18,472,739)	(14,391,110)	(14,366,469)	(14,343,736)	(14,322,641)	(14,303,182)	(14,285,133)	(14,243,721)	(15,555,171)	(14,246,426)	(14,245,082)
Discount Factor, (P/F,i*,n)	1.0000	0.9259	0.8573	0.7938	0.7350	0.6806	0.6302	0.5835	0.5403	0.5002	0.4632
Discounted Cash Flow	(18,472,739)	(13,325,102)	(12,316,951)	(11,386,520)	(10,527,569)	(9,734,506)	(9,002,067)	(8,311,074)	(8,295,921)	(7,126,760)	(6,598,229)
NPV @ i* =	(159,774,038)	not attractive									
DCFROR =		8%									
Equation for DCFROR											
result	Not attractive										

End of Year	11	12	13	14	15	16	17	18	19	20	
Production tonnes Anhydrous Ammonia	55	55	55	55	55	55	55	55	55	55	
x Sales Price, $/metric ton	553.982	553.982	553.982	553.982	553.982	553.982	553.982	553.982	553.982	553.982	
Production tonnes Oxygen (O2)	71	71	71	71	71	71	71	71	71	71	
Sales Price $/metric ton	40	40	40	40	40	40	40	40	40	40	
Sales Revenues	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	205890108.9
(+) Salvage Value	0	0	0	0	0	0	0	0	0	0	
(-) Royalties	0	0	0	0	0	0	0	0	0	0	
Net Revenues	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	10,294,505	
(-) Other Op Costs	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	(21,544,829)	
(-) Depreciation	(735,467)	(731,080)	(726,727)	(717,881)	(740,236)	(735,484)	(730,810)	(727,580)	(724,467)	(384,335)	
(-) Amortization	0	0	0	0	0	0	0	0	0	0	
(-) Depletion	0	0	0	0	0	0	0	0	0	0	
(-) Loss Forward	0	0	0	0	0	0	0	0	0	0	
(-) Writeoff	(136,597)	0	0	0	(416,671)	0	0	0	0	(540,257)	
Taxable Income	(12,122,358)	(11,981,404)	(11,977,051)	(11,967,984)	(12,407,230)	(11,985,807)	(11,981,133)	(11,977,903)	(11,974,791)	(12,174,916)	
(-) Tax @ 25%	(3,030,597)	(2,995,351)	(2,994,263)	(2,991,996)	(3,101,808)	(2,996,452)	(2,995,283)	(2,994,476)	(2,993,698)	(3,043,729)	
Net Income	(15,152,955)	(14,976,755)	(14,971,314)	(14,959,981)	(15,509,038)	(14,982,259)	(14,976,417)	(14,972,379)	(14,968,489)	(15,218,644)	
(+) Depreciation	735,467	731,080	726,727	717,881	740,236	735,484	730,810	727,580	724,467	384,335	
(+) Amortization	0	0	0	0	0	0	0	0	0	0	
(+) Depletion	0	0	0	0	0	0	0	0	0	0	
(+) Loss Forward	0	0	0	0	0	0	0	0	0	0	
(+) Writeoff	136,597	0	0	0	416,671	0	0	0	0	540,257	
(-) Working Capital	0	0	0	0	0	0	0	0	0	0	
(-) Fixed Capital	(291,588)	0	0	0	(891,099)	0	0	0	0	0	
Cash Flow	(14,572,505)	(14,245,674)	(14,244,588)	(14,242,319)	(15,043,230)	(14,246,775)	(14,245,607)	(14,244,799)	(14,244,021)	(14,294,052)	
Discount Factor, (P/F,i*,n)	0.4289	0.3971	0.3677	0.3405	0.3152	0.2919	0.2703	0.2502	0.2317	0.2145	
Discounted Cash Flow	(6,249,899)	(5,657,155)	(5,237,705)	(4,848,955)	(4,742,254)	(4,158,498)	(3,850,145)	(3,564,747)	(3,300,512)	(3,066,765)	

Ammonia Sensitivity Analysis		
NH3 Sales rate ($/ton)	Percent Variation	NPV @ 8%
428.077	-15%	-188,313,131
453.258	-10%	-182,658,866
478.439	-5%	-176,937,659
503.62	0%	-171,137,754
528.801	5%	-165,495,245
553.982	10%	-159,774,038
579.163	15%	-153,962,378

Fixed Capital Sensitivity Analysis		
Percent Variation	Fixed Capital	NPV
-15%	15,701,828	-168,366,843
-10%	16,625,465	-169,290,480
-5%	17,549,102	-170,214,117
0%	18,472,739	-171,137,754
5%	19,396,376	-172,061,391
10%	20,320,013	-172,985,028
15%	21,243,650	-173,908,665

Utility Cost Sensitivity Analysis		
Varied base	% variation	Npv @ i = 8%
$11,080,644.68	-15%	-134,156,295
$11,732,447.30	-10%	-143,995,518
$12,384,249.93	-5%	-153,834,740
$13,036,052.56	0	-171,137,754
$13,687,855.19	+5%	-173,513,185
$14,339,657.82	+10%	-183,352,407
$14,991,460.44	+15%	-193,191,630

Tornado Chart Variability				
Criteria	NPV Min ($1.0x10^6)	NPV Base ($1.0x10^6)	NPV Max ($1.0x10^6)	Variation (+/-)
Ammonia Sales	-182.66	-171.14	-159.77	10%
Utilities	-173.51	-171.14	-153.83	5%
Fixed Capital	-172.99	-171.14	-169.29	10%

A	B	C
Fixed Capital	18472739	NPV
-15%	15701828	(168,366,843)
-10%	16625465	(169,290,480)
-5%	17549102	(170,214,117)
0%	18472739	(171,137,754)
5%	19396376	(172,061,391)
10%	20320013	(172,985,028)
15%	21243650	(173,908,665)

A	B	C
Plant life		NPV
-25%	15	(156,739,754)
0%	20	(171,137,754)

MACRS Depreciation

Year	20 year
1	0.05
2	0.095
3	0.0855
4	0.077
5	0.0693
6	0.0623
7	0.059
8	0.059
9	0.0591
10	0.059
11	0.0591
12	0.059
13	0.0591
14	0.059
15	0.0591
16	0.0295

Electrolyzer Depreciation	
year	2,764,397.65
1	138,219.88
2	262,617.78
3	236,356.00
4	212,858.62
5	191,572.76
6	172,221.97
7	163,099.46
Total Depreciation	1,376,946.47
Writeoff	1,387,451.18
Replacement cost	691,099.41
8	34,554.97
9	65,654.44
10	59,089.00
11	53,214.65
12	47,893.19
13	43,055.49
14	40,774.87
15	40,774.87
16	40,843.98
Total Depreciation	425,855.46
Writeoff	265,243.95

PSA Depreciation	
year	291,588.02
1	14,579.40
2	27,700.86
3	24,930.78
4	22,452.28
5	20,207.05
6	18,165.93
7	17,203.69
8	17,203.69
9	17,232.85
10	17,203.69
Total Depreciation	196,880.23
Writeoff	94,707.79
Replacement Cost	291,588.02
11	14,579.40
12	27,700.86
13	24,930.78
14	22,452.28
15	20,207.05
16	18,165.93
Total Depreciation	128,036.30
Writeoff	163,551.72

PSA Buffer Tank	
year	1,503,594.90
1	75,179.74
2	142,841.52
3	128,557.36
4	115,776.81
5	104,199.13
6	93,673.96
7	88,712.10
8	88,712.10
9	88,862.46
10	88,712.10
11	88,862.46
12	88,712.10
13	88,862.46
14	88,712.10
15	88,862.46
16	44,356.05
total depreciation	1,503,594.90
Writeoff	0.00

Reactor Depreciation	
year	61,118.74
1	3,055.94
2	5,806.28
3	5,225.65
4	4,706.14
5	4,235.53
6	3,807.70
7	3,606.01
8	3,606.01
9	3,612.12
10	3,606.01
11	3,612.12
12	3,606.01
13	3,612.12
14	3,606.01
15	3,612.12
16	1,803.00
Total Depreciation	61,118.74
Writeoff	0.00

Compressor Depreciation

	PSA	Ammonia	Electrolyzer
year	14,202.70	2,534,853.97	1,094,474.92
1	710.14	126,742.70	54,723.75
2	1,349.26	240,811.13	103,975.12
3	1,214.33	216,730.01	93,577.61
4	1,093.61	195,183.76	84,274.57
5	984.25	175,665.38	75,847.11
6	884.83	157,921.40	68,185.79
7	837.96	149,556.38	64,574.02
8	837.96	149,556.38	64,574.02
9	839.38	149,809.87	64,683.47
10	837.96	149,556.38	64,574.02
11	839.38	149,809.87	64,683.47
12	837.96	149,556.38	64,574.02
13	839.38	149,809.87	64,683.47
14	837.96	149,556.38	64,574.02
15	839.38	149,809.87	64,683.47
16	418.98	74,778.19	32,287.01
Total Depreciation	14,202.70	2,534,853.97	1,094,474.92
Writeoff	0.00	0.00	0.00

Separator Depreciation			Filter
	Electrolyze	Ammonia	
year	$270,304.3	2,884,28	636.00
1	13,515.22	144,214.	31.80
2	25,678.91	274,006.	60.42
3	23,111.02	246,606.	54.38
4	20,813.43	222,089.	48.97
5	18,732.09	199,880.	44.07
6	16,839.96	179,690.	39.62
7	15,947.95	170,172.	37.52
8	15,947.95	170,172.	37.52
9	15,974.98	170,461.	37.59
10	15,947.95	170,172.	37.52
11	15,974.98	170,461.	37.59
12	15,947.95	170,172.	37.52
13	15,974.98	170,461.	37.59
14	15,947.95	170,172.	37.52
15	15,974.98	170,461.	37.59
16	7,973.98	85,086.3	18.76
Total Depre	270,304.30	2,884,28	636.00
Writeoff	0.00	0.00	0.00

Storage Vessel

	H2O	Ammonia	O2
year	$48,681.83	$5,768,568.01	$348,825
1	2,434.09	288,428.40	17,441.2
2	4,624.77	548,013.96	33,138.4
3	4,162.30	493,212.56	29,824.5
4	3,748.50	444,179.74	26,859.5
5	3,373.65	399,761.76	24,173.6
6	3,032.88	359,381.79	21,731.8
7	2,872.23	340,345.51	20,580.7
8	2,872.23	340,345.51	20,580.7
9	2,877.10	340,922.37	20,615.6
10	2,872.23	340,345.51	20,580.7
11	2,877.10	340,922.37	20,615.6
12	2,872.23	340,345.51	20,580.7
13	2,877.10	340,922.37	20,615.6
14	2,872.23	340,345.51	20,580.7
15	2,877.10	340,922.37	20,615.6
16	1,436.11	170,172.76	10,290.3
Total Depre	48,681.83	5,768,568.01	348,825.
Writeoff	0.00	0.00	0.00

Heat Exchangers Depreciation

	E-201	E-202	Ammonia 1	Ammonia 2
year	162,995.82	297,690.06	165,547.4	125,750.82
1	8,149.79	14,884.50	8,277.37	6,287.54
2	15,484.60	28,280.56	15,727.01	11,946.33
3	13,936.14	25,452.50	14,154.31	10,751.69
4	12,550.68	22,922.13	12,747.15	9,682.81
5	11,295.61	20,629.92	11,472.44	8,714.53
6	10,154.64	18,546.09	10,313.60	7,834.28
7	9,616.75	17,563.71	9,767.30	7,419.30
8	9,616.75	17,563.71	9,767.30	7,419.30
9	9,633.05	17,593.48	9,783.85	7,431.87
10	9,616.75	17,563.71	9,767.30	7,419.30
11	9,633.05	17,593.48	9,783.85	7,431.87
12	9,616.75	17,563.71	9,767.30	7,419.30
13	9,633.05	17,593.48	9,783.85	7,431.87
14	9,616.75	17,563.71	9,767.30	7,419.30
15	9,633.05	17,593.48	9,783.85	7,431.87
16	4,808.38	8,781.86	4,883.65	3,709.65
Total De	162,995.82	297,690.06	165,547.4	125,750.82
Writeoff	0.00	0.00	0.00	0.00

Pumps Depreciation

	Electrolyzer
year	$135,861.57
1	6,793.08
2	12,906.85
3	11,616.16
4	10,461.34
5	9,415.21
6	8,464.18
7	8,015.83
8	8,015.83
9	8,029.42
10	8,015.83
11	8,029.42
12	8,015.83
13	8,029.42
14	8,015.83
15	8,029.42
16	4,007.92
Total Depreciati	135,861.57
Writeoff	0.00

Operation Cost

Operating Cost			
		Equation	
CRM	$14,218.53		raw material
CWT	$0.00		waste treatment
CUT	$13,036,052.56		utility cost
COL	$781,284.00		op labor
COM	$0.00		
FCI	$18,472,738.75		fixed capital
Total manufacturing cost	$21,509,831.73	0.18FCI+2.73COL+1.23(CUT+CWT+CRM)	
	$21,492,342.94		
	$23,095,777.40		
	$6,420,058.97		

operator works	49	weeks/yr		Reactor	2
	5	shifts/week		Tower	2
	8	hr / shift		Compressor	3
	245	shifts/(operator*yr)		Heat Exchangers	4
	3	shifts/day		Mixer	1
plant operation	24	hr/day			
	365	day/yr			
	1095	operating shifts/yr			
	4.469387755	operators			
Nnp	12				
Nol	3.008321791	(6.29+ 31.7P^2 +.23*Nnp)^0.5			
op labor	13.44535658				
total op labor	14				
salary/yr(2020)	$55,806.00	Values provided by the department of labor			
total op labor/equipment	$781,284.00				

	Price	Unit
Water	1.94	$/1000 gallons
Water	0.00194	$/gallons
Electricity	0.0654	$/kWh
Steam		
Service factor	0.9583333333	

Pump (electrolyzer unit)	
dp (psi)	194.952
Flowrate (gpm)	567
Hydraulic HP	64.45352
Pump efficiency	0.80000
Brake HP	80.56690
Motor efficiency	0.91000
Purchased HP	88.53505
Power (kWatt)	66.02059

Water		
Electrolyzer Hex (E-202)		
mH2O (gallons/hr)	2058.43829	$33,524
	Total	$33,524

Electricity		
Electrolyzer		
Electrolyzer Stacks		Cost/yr
Power (kWatt)	1457.6	$800,271
Pump		
Power (kW)	66.02059	$36,247
Separator		
Power (kW)	18.33611111	$10,067
Compressor		
Power (kW)	365.4	$200,617
	Total	$1,047,202
PSA		
Compressor		Cost/yr
Power (kW)	5.24	2,878.03
	total	2878.03
Total operating cost	$13,036,053	
	$14,339,658	
	$11,732,447	

Ammonia Synthesis		Cost/yr
Chiller		
Power (kW)	11290	6198582.57
Compressor		
Power (kW)	10480	5753865.84
	Total	11952448.41

Fixed Capital Investment

Electrolyzer Unit	
Alkaline electrolyzer	$2,764,398
Heat Exchanger, E-201	$162,996
Heat Exchanger, E-202	$297,690
Pumps	$135,862
Separator	$270,304
Compressor	$1,094,475
H2O storage tank	$48,682
O2 Storage tank	$348,826
Total	$5,123,232

PSA Unit	
6 tanks	$291,588
Compressor	$14,202
Buffer Tank	$1,503,595
Total	$1,809,385

Ammonia Synthesis	
Reactor	61119
Compressor	2534854
mixer	0
Chiller	125751
Heat exchanger	165547
Separator	2884283
Storage tank	5768568
Total	11540122

Total	$18,472,739

Raw materials			
Water			
CRM			
Electrolyzer		Cost/yr	
mH2O (gallons/h	873.0362101	14218.52963	
PSA	NO RAW MATERIALS		
R-134a	40115 kg	583693.68	one time
silicia gel	55kg/10 yrs	100	per decade

Waste from Electrolyzer water	
CWT	0
PSA	NO WASTE
Negligible waste from ammonia synthesis	

Appendix V

PSA Design Equations

Amount of Oxygen Adsorbed

$$m_{oxygen} = t_{cycle} * \dot{n}_{total} * x_{O_2} * MW_{O_2}$$

Amount of Adsorbent

$$m_{adsorbent} = \frac{m_{O_2}}{Adsorption\ Capacity * \rho_{O_2}}$$

Volume of Adsorbent

$$V_{adsorbent} = \frac{m_{adsorbent}}{\rho_{Bulk}}$$

L/D = 3 or 4.5

Volume per tank

$$V_{tank} = \frac{V_{adsorbent}}{N_{tanks}}$$

Diameter of Tank

$$D = \sqrt[3]{\frac{V_{tank} * 4}{\pi * \frac{L}{D}}}$$

Height of Tank

$$h = D * \frac{L}{D}$$

Pressure Drop Across the Bed

$$\frac{\Delta P}{L} = \frac{150\mu(1-\epsilon)^2 u_0}{\epsilon^3 d_p^2} + \frac{1.75(1-\epsilon)\rho u_0^2}{\epsilon^3 d_p}$$

$\Delta P =$ the pressure drop,

$L =$ the height of the bed,

$\mu =$ the fluid viscosity,

$\varepsilon =$ the void space of the bed,

$u_0 =$ the fluid superficial velocity,

$d_p =$ the particle diameter

$\rho =$ the density of the fluid.

PSA Separation Tank Sizing

PSA Sizing

Constants			Reference Values		
Tatm	298.15	K	Superficial Velocity	0.007	m/s
Patm	1.01	Bar	Adsorption Capacity	1.3	cm3 O2 /g CMS
MW N2	28.01	g/mol	Feed Density	1.153	kg/m3
MW O2	32.00	g/mol	Bulk Density	0.7	g/ml
Air Rho STP	1.153	kg/m3	Oxygen Rho 6bar 28(	4.2	kg/m3
N2 comp	0.79		N2 Rho 6bar 280C	3.68	kg/m3
O2 Comp	0.21		Air Rho 6bar 280C	3.79	kg/m3
Water MW	18.02	g/mol	Water Rho STP	997	kg/m3
MWavg Air (STP)	28.97	g/mol (lb/lbmol)	H2O rho (gas) *	0.0762	kg/m3

Operating Conditions		
Pressure Inlet	6.00	bar
Pressure Outlet	6.00	bar
N2 Req. Prod	475.90	g/s
Cycle Time	240.00	s

360 cycles per day

453.6	gmol/lbmol
0.00629	bbl/L
6.29	bbl/m3
0.062428	lb/ft3 per 1 kg/m3

RhoN2 1bar 227c	0.68
RhoN2 1bar 327C	0.56
RhoN2 10bar 227(	6.74
RhoN2 10bar 327(	5.59
1bar interpolate	0.62
10bar interpolate	6.13

Molar Flow	*Assuming Filter 100% efficient at removing water		
Pre Filter	Total molar Flow	170.81	lbmol/h
	Molar Flow H20	0.12	lbmol/h
	Molar Flow O2	35.85	lbmol/h
	Molar Flow N2	134.85	lbmol/h
Post Filter	Total Molar Flow	170.69	lbmol/h
	Molar Flow H20	0.00	lbmol/h
	Molar Flow O2	35.85	lbmol/h
	Molar Flow N2	134.85	lbmol/h
	Split N2 Product	44.97	lbmol/h
	Split O2 Vent	11.93	lbmol.h

Volumetric Flow			
Pre Filter, Pre Compre	Feed Vol. Flow	292,434.35	bbl/day
	Feed Vol. Flow	292,434.33	bbl/day
Post Filter Post Compr	Feed Vol. Flow	89,007.14	bbl/day
	Feed Vol. Split	29,670.00	bbl/day
	Split O2 Vent	6,223.78	bbl/day
	Split Prod. Flow	23,445.81	bbl/day
	Product Flow	70,337.43	bbl/day

1 Tank Sizing		
Post Filter Molar F	77,425.06	gmol/h
Post Filter Mass F	2,233.55	kg/h
Post Filter Vol. Fee	589,607.43	L/h 3bar 280C
Pre Filter Vol Feed	1,937,164.32	L/h STP
Volumetric Feed R	0.16	m3/s
Cross-Sectional A	23.40	m2
Diameter	5.46	m
Amount O2 Adsort	34.69	kg O2
Mass CMS	6,352.83	kg CMS
Volume CMS	9.08	m3 CMS
Bed Height	0.39	m

Tank Sizing		
Total Feed Rate	77,425.06	mol/h
Feed Rate of Air	2,233.55	kg/h
Feed Rate of Air	589,607.43	L/h
# of feed splits	3.00	
Volumetric Feed Rate	0.05	m3/s
Cross-Sectional Area	7.80	m2
Diameter	3.15	m
Amount O2 Adsorbed	11.56	kg O2
Mass CMS	2,117.61	kg CMS
Volume CMS	3.03	m3 CMS
Bed Height	0.39	m

https://www.sciencedirect.com/topics/engineering/bed-adsorbers

pick Cross A		Some L/Ds		3	4.5	<--- Deceased Area		
for suitable L/D								
	L/D=	3			4.5			
# of tanks	volume (m3 CM	Diameter (m)	C-S Area (m2)	Bed Height (m)	Diamete	C-S Area (m2)	Bed Height (m)	
1	9.08	1.57	1.93	4.70	1.37	1.47	6.16	
2	4.54	1.24	1.22	3.73	1.09	0.93	4.89	
3	3.03	1.09	0.93	3.26	0.95	0.71	4.27	
4	2.27	0.99	0.77	2.96	0.86	0.58	3.88	
5	1.82	0.92	0.66	2.75	0.80	0.50	3.60	
8	1.13	0.78	0.48	2.35	0.68	0.37	3.08	
10	0.91	0.73	0.42	2.18	0.64	0.32	2.86	

Pre Filter	Total molar Flow	170.81	lbmol/h	Total ma	4,948.45	lb/h
	Molar Flow H20	0.12	lbmol/h	Mass Flc	2.15	lb/h
	Molar Flow O2	35.85	lbmol/h	MassFlo	1,147.20	lb/h
	Molar Flow N2	134.85	lbmol/h	MassFlo	3,777.15	lb/h
Post Filter	Total Molar Flow	170.69	lbmol/h	Total Ma	4,946.29	lb/h
	Molar Flow H20	0.00	lbmol/h	Mass Flc	#REF!	lb/h
	Molar Flow O2	35.85	lbmol/h	MassFlo	1,147.20	lb/h
	Molar Flow N2	134.85	lbmol/h	Mass Flc	3,777.15	lb/h
	Split N2 Product	44.95	lbmol/h	Split N2	1259.05	lb/h
	Split O2 Vent	11.95	lbmol.h	Split O2	382.40	lb/h
				Split Air	1648.76	lb/h

	O2 in split O2 vnt		380.49	lb/hr		
	O2 in N2 split		1.44	lb/hr		
	total o2		1,145.78			
					o2vent	n2vent
	n2 in split o2vent		1.67		382.16	1,259.68
	n2 in product		1,258.24			
total n2		3,779.74				

PSA Tank Pressure Drop

Ergun Equation

dP/L = [(150*mu*(1-sigma)^2 * uo)/(sigma^3 * Dp^2)]+[(1.75*(1-sigma)*rho*uo^2)/(sigma^3 * Dp)]

dP = [x + y] *L

dP	0.1981607356	Pa
x	0.07589538517	
y	-0.01512142791	

dP	0.00	bar
Po	6.00	bar
Pf	6.00	bar

Po	6 bar
T	280C

non- P/T dependent Constants			
Ac	0.93	m2	area
L	3.26	m	height
phi	0.40		porosity
sigma	1.21	m3	void space
uo	0.01	m/s	superficial velocity
Dp	0.00	m	particle diameter
gc	1.00	kg N / m s2	

P/T dependent constants			
rho	4.73	kg/m3	fluid density
mu	0.00002935	kg/(m*s)	fluid viscosity

PSA Buffer Tank Sizing

Half-full residence time

$\tau = V_h / q$

L/D = 3 or 4.5

Diameter of Tank

$$D = \sqrt[3]{\frac{V_{tank} * 4}{\pi * \frac{L}{D}}}$$

Height of Tank

$$h = D * \frac{L}{D}$$

Buffer Tank Design And Costing

Utilizing info from "Buffer Tank Design for Acceptable Control Performance" wanting an averaging level control with a slow level controller

Synonyms: Surge tanks, intermediate storage vessels, holdup tanks, surge drums, accumulators, or inventories

GPSA: using Horizontal cylindrical high pressure storage tanks considering our N2 has an approx. pressure of 6 bar and HCSTs go from 1-70 bar

Denotation	Variables	Equations
Tr	Residence Time	Tr = V/qout
Trh	Half-Full Res. Time	Vo=V*1.1
V	Tank Volume	dV/dt = qin - qout
Vo	Tank Volume (accounting for overflow)	qout(s) = h(s) * qin(s)
q	Nominal Flow	Vsphere = (pi/6)*D^3
h	Flow-Rate Disturbance (Estimated)	Vcylinder = (pi/4)*D^2*L
L	internal cylindrical tank length/height	Vtank = Vsph+Vcyl
D	internal tank diameter	

Operating Conditions				
Temperature In/Out	280.00	Deg C		
Pressure In/Out	6.00	bar	87.02	psi
N2 Req. Prod	475.90	g/s	16.99	mol/s

Constants		
MW N2	28.01	g/mol
1 bar =	14.5038	psi
N2 density @ 6 bar	3.66616	kg/m3

From "Buffer Tank Design..."

Our Values		
Trh	7	min
qout	0.13	m3/s
V	109.04	m3
Vo	119.94	m3
qin max	0.27	m3/s
h	0.48	-

Tank Sizing (model: cylinder w/ hemispherical caps)		
L/D ratio =	3	4.5
Volume (m3)	119.94	119.94
Diameter (m)	3.466353389	3.091907541
CS Area (m2)	9.437034739	7.50832181
Height, L (m)	10.39906017	13.91358394
Vsph (m3)	21.8080649	15.47669122
Vcyl (m3)	98.13629203	104.4676657
Vtank (m3)	119.9443569	119.9443569
Vreq = Vtank	True	True

PSA Enthalpy Streams

Component	Temp (K)	Temp (Deg C)	Specific h (kJ/kmol)
Air	298	25	8260.51
	550	277	16070.82
	560	287	16372.97
	553	280	16166.00
Oxygen, O2	298	25	8682.00
	550	277	16338.00
	560	287	16654.00
	553	280	16432.80
Nitrogen, N2	298	25	8669.00
	550	277	16064.00
	560	287	16363.00
	553	280	16153.70
Water Vapor, H2O	298	25	9904.00
	550	277	18601.00
	560	287	18959.00
	553	280	18708.40

Stream	Mass Flow (lbmol/h)	Temp (Deg C)
Wet Inlet Air	170.81	24.98
Dried Air	170.69	280.00
Split Dry Air	56.90	280.00
Dry O2 total	35.85	279.85
Split O2	11.95	279.85
N2 total	134.85	279.85
Split N2	44.95	279.85
H2O waste	0.12	24.85

Component	MW (lb/lbmol)	
Air	28.97	
O2	32	
N2	28.01	
H2O	18.02	
1kg =	2.20	lb
1 BTU =	1.05506	kJ

Air		
kmol/h, n(Air)	nh(Air) (kJ/h)	(BTU/lbm)
77.48	640019.47	122.59
77.43	1251655.86	239.91
25.81	417218.62	239.91
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00

H2O		
kmol/h, n(H2O)	nh(H2O) (kJ/h)	(BTU/lbm)
0.05	537.15	0.43
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.05	537.15	0.43

O2		
kmol/h, n(O2)	nh(O2) (kJ/h)	(BTU/lbm)
16.26	141180.66	349.93
16.26	267218.79	220.78
5.42	89072.93	220.78
16.26	267218.79	220.78
5.42	89072.93	220.78
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00

N2		
kmol/h, n(N2)	nh(N2) (kJ/h)	(BTU/lbm)
61.17	530256.76	133.06
61.17	988073.43	247.94
20.39	329357.81	247.94
0.00	0.00	0.00
0.00	0.00	0.00
61.17	988073.43	247.94
20.39	329357.81	247.94
0.00	0.00	0.00

Stream	Mass Flow (lbmol/h)	Air n(Air)/nTot	O2 n(O2)/nTot	N2 n(N2)/nTot	H2O n(H2O)/nTot
Wet Inlet Air	170.81	1.00	0.2098789434	0.789460963	0.0007
Dried Air	170.69	1.00	0.2100259616	0.7900139728	0
Split Dry Air	56.90	1.00	0.2100259616	0.7900139728	0
Dry O2 total	35.85	0.00	1	0	0
Split O2	11.95	0.00	1	0	0
N2 total	134.85	0.00	0	1	0
Split N2	44.95	0.00	0	1	0
H2O waste	0.12	0.00	0	0	1

Stream Specific Enthalpy (kJ/kmol)					
Air	O2	N2	H2O	Total	Avg Air & Total
8260.5058	1822.168987	6843.837088	6.9328	8672.938875	8466.722338
16165.99729	3451.314622	12761.64871	0	16212.96333	16189.48031
16165.99729	3451.314622	12761.64871	0	16212.96333	16189.48031
0	16432.8	0	0	16432.8	16432.8
0	16432.8	0	0	16432.8	16432.8
0	0	16153.7	0	16153.7	16153.7
0	0	16153.7	0	16153.7	16153.7
0	0	0	9904	9904	9904

Specific Enthalpy (BTU/lbmol)	Stream
3640.025419	Wet Inlet Air
6960.20461	Dried Air
6960.20461	Split Dry Air
7064.812961	Dry O2 total
7064.812961	Split O2
6944.821888	N2 total
6944.821888	Split N2
4257.941894	H2O waste

Total Mol Flow (kmol/h)	Enthalpy, h (kJ/h)	Enthalpy, h (kJ/kmol)	Enthalpy, h (BTU/lbm)	
77.48	671974.56	27255.00	122.59	483.42
77.43	1255292.22	32586.50	239.91	468.72
25.81	418430.74	32586.50	239.91	468.72
16.26	267218.79	16432.80	220.78	220.78
5.42	89072.93	16432.80	220.78	220.78
61.17	988073.43	16153.70	247.94	247.94
20.39	329357.81	16153.70	247.94	247.94
0.05	537.15	9904.00	0.43	0.43

Electrolyzer Design Equations

$$\Delta G = z \cdot F \cdot Vrev$$

$$Vtn = \frac{\Delta H}{z \cdot F}$$

$$Vrev = \frac{\Delta G}{z \cdot F}$$

$$Vcell = Vrev + Vact + Vohm$$

$$Vact = s \cdot log\left(\frac{t1 + \frac{t2}{T} + \frac{t3}{T}}{A} \cdot I + 1\right)$$

$$Vohm = \frac{r1 + r2 \cdot T}{A} \cdot I$$

$$\eta F = \frac{\left(\frac{I}{A}\right)^2}{f1 + \left(\frac{I}{A}\right)^2} \cdot f2$$

$$n = \frac{Vtn}{Vcell}$$

$$nH2O = nH2 = 2 \cdot nO2$$

$$nH2 = nF \cdot \frac{nc \cdot I}{z \cdot F}$$

$$m = \frac{I \cdot t \cdot M}{z \cdot F}$$

$$mef = \frac{m \cdot nF \cdot nc}{t}$$

$$I = j \cdot A \cdot 100^2$$

$$Q = nc \cdot Vcell \cdot I(1 - n)$$

$$P = I \cdot Vcell \cdot nc$$

ΔG = Gibbs free energy

z = Number of electron transfer

F = Faraday's number

$Vrev$ = Reversible voltage

Vtn = Thermoneutral voltage

ΔH = Enthalpy

$Vact$ = Activation voltage

$Vohm$ = Ohmic voltage

s = Coefficient for overvoltage in electrodes

t = time

$t1/t2/t3$ = Coefficients for overvoltage in electrodes

r = Ohmic resistance parameter

f = Faraday efficiency parameter

nc = Number of cells

I = Current

T = Operating Temperature

n = Efficiency of electrolyzer

nF = Current efficiency in the cell/Faraday's efficiency

$nH2/nH20/nO2$ = Molar flow rates

m = Total Mass of H2

M = Molecular weight

mef = Total mass flow rate of H2

A = Area of electrodes

j = Current density

Q = Heat generated

P = Power of the electrolyzer

Table: Electrolyzer Design Parameter

Parameter	unit	Value
ΔG	kJ	237.2
ΔH	kJ	285.8
F	C/mol	96485
s	V	0.185
$t1$	$A^{-1}m^2$	1.002
$t2$	$A^{-1}m^2\,°C$	8.424
$t3$	$A^{-1}m^2\,°C$	247.3
$r1$	Ωm^2	$8.05x10^{-5}$
$r2$	$\Omega m^2\,°C^{-1}$	$-2.5x10^{-7}$
$f1$	mA^2cm^{-4}	150
$f2$		0.990
nc		2490
z		2
j	A/cm^2	0.8
MH2	g/mol	2.016
MH2O	g/mol	18.02
MO2	g/mol	16.0
T	°C	40
A	m^2	0.5
t	s	86400

Table: Electrolyzer Matlab Results

Parameter	Value	Unit
T	40	℃
I	4000	A
A	0.5	m^2
Vrev	1.2292	V
Vact	1.6684	V
Vohm	0.0177	V
Vcell	2.9153	V
Vtn	1.4811	V
m	$3.61x10^3$	g
mef	103.1	g/s
mH20	9.41	g/s
mO2	808.7	g/s
Q	$7.17x10^5$	W
P	1.46	MW
n	0.508	
nF	0.9898	
nc	2490	
nStacks	125	
xH2O	0.0115	
xO2	0.9885	

Matlab Code

MATLAB 5.0 MAT-file, Platform: PCWIN64, Created on: Thu Apr 2 04:30:40 2020 IM%xœãc``°b6 æ€Ò À
å3Â1#ƒ#æ„ŠCÀ{EÝ%xœãc``0b6 æ€Ò À
å3Â1#ƒXœ…ái#È0xœãc``pb6 æ€Ò À
å3"av ö0*É/IÌaà„Êß2ˆ_µdw¤gã4'xœãc``0b6 æ€Ò À
å3Â1#ƒ'fa`bXÀÏÀ‡b*xœãc``°b6 æ€Ò À
å3Â1#ƒ/æ„Š[ÎùyUFÁ/Qé&xœãc``0b6 æ€Ò À
å3Â1
ƒo¸¿¥ä3¯.xœãc``pb6 æ€Ò À
å3"a˜ox†'æ„Êg{ÜI~ÉläN«G+xœãc``°b6 æ€Ò À
å3Â13ƒ_†'TœçÎ¦©ö8ñ}/xœãc``pb6 æ€Ò À
å3"aœ_†'AfTþý¹Æ[©ž_Þ0xœãc``pb6 æ€Ò À
å3"av öË0ÊÏ/-aà„Ê7ÈoŽÛñÀfO+xœãc``°b6 æ€Ò À
å3Â13ƒ_¾'TœçÎ¦V{9Vt*xœãc``°b6 æ€Ò À
å3Â1#Cæ„ŠÛM¼.öÊÖÌ.Å#&xœãc``0b6 æ€Ò À
å3Â1C€!Hœ…ál7#BH&xœãc``0b6 æ€Ò À
å3Â1C€Hœ…¡¡7šÓX+xœãc``°b6 æ€Ò À
å3Â13C€o8'TÜûúã¦† ïö?«*xœãc``°b6 æ€Ò À
å3Â1#C æ„Š«½½-Û(±Á/Ðb+xœãc``°b6 æ€Ò À
å3Â1
C ‡'?'T\íímÙF‰
>-.+xœãc``°b6 æ€Ò À
å3Â13C ¿'T\íímÙF‰9=Õ+xœãc``°b6 æ€Ò À
å3Â1
C`zj'TüE‰Ó§¸GªŽJxS*xœãc``°b6 æ€Ò À
å3Â1#Cæ„Š‡<^:ûÈ3Ä
'xœãc``°b6 æ€Ò À
å3Â1#Cæ„Š§À¤b-'/xœãc``pb6 æ€Ò À
å3"a?$¿$1Ç/ßˆÊ |®ñVj‡¥stñ/xœãc``pb6 æ€Ò À

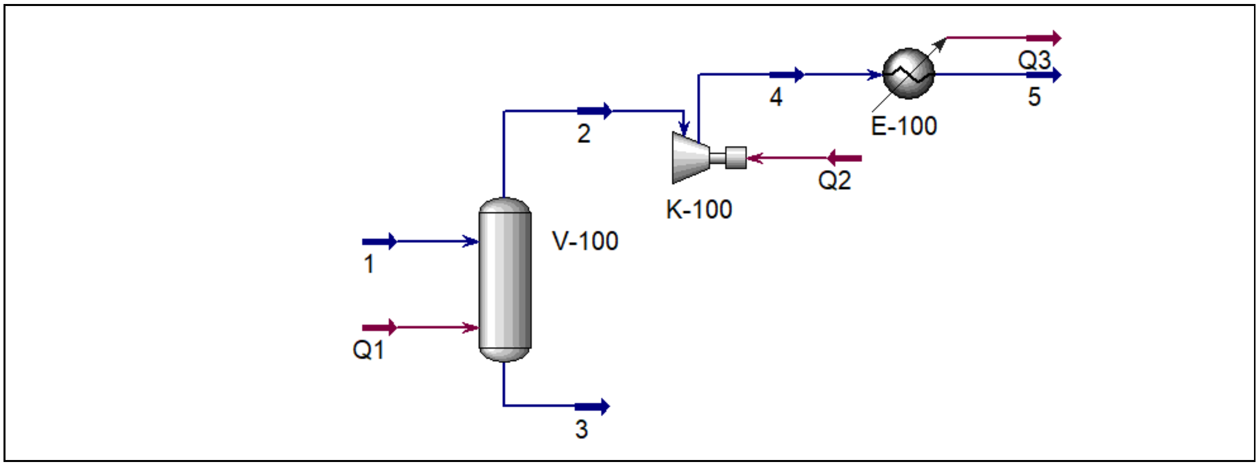
å3"a?$¿$1'×ßˆÊ/dbnlqíteÿ*xœãc``°b6 æ€Ò À
å3Â1#C□æ„Š{_□ÜÔÄî2Cs,xœãc``°b6 æ€Ò À
å3Â1
CXbr 'Tü(ïú5k6þ²IøÑ+xœãc``°b6 æ€Ò À
å3Â1
CX~F.'T|AWß"Oò"ìL˜+xœãc``°b6 æ€Ò À
å3Â1
CXQj'Tœ□Á!º1€Õ =Ö+xœãc``°b6 æ€Ò À
å3Â13CXI'T<-ÝO+{Ów{>O.xœãc``pb6 æ€Ò À
å3"a□Xxr~n□æ„Ê¦´›¼U-rY"Ä&xœãc``0b6 æ€Ò À
å3Â1CŠ;Hœ…aÂ<fmJ&xœãc``0b6 æ€Ò À
å3Â1CŠHœ…!#†…â+xœãc``°b6 æ€Ò À
å3Â1CJ('T|3ïM)#Ã5ö4ä8/xœãc``pb6 æ€Ò À
å3"a□\Jxr~n'TÞí"Ò"§*¢a®)xœãc``°b6 æ€Ò À
å3Â1Cš!'Tü?xŸuD€h+xœãc``°b6 æ€Ò À
å3Â1Cš'T|□ûÃ*'uïí7vV*xœãc``°b6 æ€Ò À
å3Â1#C.□æ„Š›®¿ýÃx□5S+xœãc``°b6 æ€Ò À
å3Â13C®¿'TœçÎ¦«ö:Ã+xœãc``°b6 æ€Ò À
å3Â13Cnj'T|§"tS'ÎR{=©.xœãc``pb6 æ€Ò À
å3"a□XnZN~9□æ„Ê«ëk¯NYj[…/xœãc``pb6 æ€Ò À
å3"a□\n†'Af'TþH¥x±Â¦ZŒý0xœãc``pb6 æ€Ò À
å3"av ÎÍ0ÊÏ/-aà„Êgð/XP~YÉh4¼*xœãc``°b6 æ€Ò À
å3Â1#C□æ„Šº–□u|`.ŸU(xœãc``0b6 æ€Ò À
å3Â13Cž«3
ÃNN F$+xœãc``°b6 æ€Ò À
å3Â1Cž'LÝlÛ¿ºkÞÛ5³+xœãc``°b6 æ€Ò À
å3Â13Cž‡'Tœ÷Î¦©ö9~+xœãc``°b6 æ€Ò À
å3Â1
Cž‡'?'Tœ÷Î¦©ö>nÎ+xœãc``°b6 æ€Ò À
å3Â13Cž¿'TüÁ¼Þ'ô G{>Ž&%xœãc``0b6 æ€Ò À
å3Â1C^2□dd¨òÃ¶,xœãc``°b6 æ€Ò À
å3Â1
C^n~'T|–âïsç~ÏvO[^*xœãc``°b6 æ€Ò À

å3"a□\^qIbr6P¤È;Íu+xœãc``°b6 æ€Ò À
å3Â1C'!'TüÌ•
g)Q{5ò,xœãc``°b6 æ€Ò À
å3Â1C''T¼÷íÖß□MØ?3ü*xœãc``°b6 æ€Ò À
å3Â1#C1□æ„Š¯s□X%²î¸=4^%xœãc``0b6 æ€Ò À
å3Â1#C Xœ…¡!□'ç³+xœãc``°b6 æ€Ò À
å3Â1C‰!'TüjÅK5CŽö8ç+xœãc``°b6 æ€Ò À
å3Â1C‰'Tœ‡I»]ì¦‚„„3*xœãc``°b6 æ€Ò À
å3Â1C‰1'T|ÖL x™ç:îº.xœãc``pb6 æ€Ò À
å3"a□XI~Ib□æ„ÊÏg`ÙéY7-0xœãc``pb6 æ€Ò À
å3"av ®È0ÊÏ/-aà„ÊÏ¹ñ";kB»=oTœ,xœãc``°b6 æ€Ò À
å3Â13CE¾'T|žÄ…ð}
ßÛ@¢$xœãc``0b6 æ€Ò À
å3Â1#C□fÒL@ã

Name	Value
A	0.5000
dG	237200
dH	285800
dU	0.0551
dWcomp	5.2860
F	96485
f1	1.5000e+04
f2	0.9900
H2total	102.9319
I	4000
m	3.6100e+03
M	2.0157
mef	0.0414
mflow	0.0418
mh20in	918.2658
mh2oout	9.4130
mO2	0.3283
MWh20	18.0153
MWO2	32
n	0.5080
nc	125
nEC	2489
nF	0.9898
nH2	0.0205
Nh2	0.0205
Nh20in	51.0656
nH2O	0.0205
Nh2oout	0.5225
nmol	1.7910e+03
nO2	5.2862e-04
No2	0.0103
nstack	125
P	1.4576e+06
P1	101325
P2	6000000
PMW	1.4576
Q	4.1205e+03
Qgen	7.1711e+05

Name	Value
QH2O	4.1205e+03
QO2	2.0603e+03
R	8.3140
r1	8.0500e-05
r2	-2.5000e-07
s	0.1850
t	86400
T	313.1500
t1	1.0020
t2	8.4240
t3	247.3000
total	102.8596
TotalmO2	808.6897
TotalNo2	25.5328
V	2.9153
Vact	1.6684
Vohm	0.0177
Vrev	1.1443e+10
Vtn	1.4811
Wcomp	1.9030e+07
xh2oout	0.0115
xo2	0.9885
z	2

O_2-H_2O separation



This *Input Summary* is generated by HYSYS

Date: Tue Mar 31 01:42:30 CDT 2020

FLUID PACKAGE: Basis-1
Property Package Type: **PengRob**
Component List - 1: / H2O / Oxygen

FLOWSHEET: Main

FLUID PACKAGE: Basis-1
UNIT OPERATION: V-100 *(Separator)*
Feed Stream = 1

Vapour Product = 2

Liquid Product = 3

Energy Stream = Q1

Diameter = 5 ft

Height = 10 ft

HeatExchanger = Duty

STREAM: 1 *(Material Stream)*

Temperature = 95 F

Pressure = 203.05278 psia

Mass Flow = 6492.10608 lb/hr

Composition Basis (In Mole Fractions): H2O = 0.0115 / Oxygen = 0.9885 /

STREAM: 2 *(Material Stream)*

Composition Basis (In Mole Fractions): H2O = 0.01 / Oxygen = 0.99 /

STREAM: 4 *(Material Stream)*

Pressure = 2900.754 psia

UNIT OPERATION: K-100 *(Compressor)*

Feed Stream = 2

Product Stream = 4

Energy Stream = Q2

CurveCollectionName = CC-0

SelectedCurveCollection = True

NumberOfCurves = 0

NumberOfCurves = 0

NumberOfCurves = 0

EffCurveType = 0

NumberOfCurves = 0

UNIT OPERATION: E-100 *(Cooler)*

Feed Stream = 4

Product Stream = 5

Energy Stream = Q3

STREAM: 5 *(Material Stream)*

Temperature = 122 F

Pressure = 2900.754 psia

INPUT SUMMARY

FLUID PACKAGE: Basis-1(Peng-Robinson)

Property Package Type: PengRob

Component List - 1: H2O /Oxygen

FLOWSHEET: Main

Fluid Package: Basis-1

UNIT OPERATION: V-100 (Separator)

Feed Stream = 1

Vapour Product = 2

Liquid Product = 3

Energy Stream = Q1

Diameter = 5 ft

Height = 10 ft

HeatExchanger = Duty

STREAM: 1 (Material Stream)
  Temperature = 95 F
  Pressure = 203.05278 psia
  Mass Flow = 6492.10608 lb/hr
  Composition Basis (In Mole Fractions):H2O = 0.0115/ Oxygen = 0.9885/
STREAM: 2 (Material Stream)
  Composition Basis (In Mole Fractions):H2O = 0.01/ Oxygen = 0.99/
STREAM: 3 (Material Stream)
STREAM: Q1 (Energy Stream)
STREAM: 4 (Material Stream)
  Pressure = 2900.754 psia
STREAM: Q2 (Energy Stream)

UNIT OPERATION: K-100 (Compressor)
  Feed Stream = 2
  Product Stream = 4
  Energy Stream = Q2
  CurveCollectionName = CC-0
  SelectedCurveCollection = True
  NumberOfCurves = 0
  NumberOfCurves = 0
  NumberOfCurves = 0
  EffCurveType = 0
  NumberOfCurves = 0

UNIT OPERATION: E-100 (Cooler)
  Feed Stream = 4
  Product Stream = 5
  Energy Stream = Q3
STREAM: Q3 (Energy Stream)
STREAM: 5 (Material Stream)
  Temperature = 122 F

Pressure = 2900.754 psia

OUTPUT SUMMARY

Case Name: O2-H2O separator with Compressor.hsc

Bedford, MA

USA Unit Set: Field

Date/Time: Tue Mar 31 01:44:34 2020

Basis-1 (Fluid Package): Component List

Fluid Package: Basis-1

COMPONENT LIST

Component List - 1 [HYSYS Databanks]

COMPONENT	TYPE	MOLECULAR WEIGHT	BOILING PT (F)	IDEAL LIQ DENSITY (lb/ft3)	CRITICAL TEMP (F)
H2O	Pure	18.02	212.0	62.30	705.5
Oxygen	Pure	32.00	-297.3	71.02	-181.1

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

COMPONENT	CRITICAL PRES (psia)	CRITICAL VOL (ft3/lbmole)	ACENTRICITY	HEAT OF FORM (Btu/lbmole)
H2O	3208	0.9147	0.3440	-1.040e+005
Oxygen	736.8	1.173	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 (lb/hr)	Out Stream	Count	Mass Flow (lb/hr)
1	Yes	6492	3	Yes	5.575
			5	Yes	6487

Total In MassFlow (lb/hr) 6492 Total Out MassFlow (lb/hr) 6492
Mass Imbalance (lb/hr) -6.800e-003 Rel Mass Imbalance Pct (%) -0.00
OVERALL ENERGY BALANCE

InStream	Count	Energy Flow (Btu/hr)	OutStream	Count	Energy Flow (Btu/hr)
1	Yes	-2.564e+05	3	Yes	-3.781e+04
Q1	Yes	6.257e+04	5	Yes	-2.906e+05
Q2	Yes	1.247e+06	Q3	Yes	1.381e+06

Total In EnergyFlow (Btu/hr) 1.053e+006 Total Out EnergyFlow (Btu/hr) 1.053e+006
Energy Imbalance (Btu/hr) -9.084 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)	IFPP (2007)	EPA (2009)

		(lb/hr)	(lb/hr)	(lb/hr)
1	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)	IFPP (2007)	EPA (2009)
		(lb/hr)	(lb/hr)	(lb/hr)
3	Yes	0.000e-01	0.000e-01	0.000e-01
5	Yes	0.000e-01	0.000e-01	0.000e-01
Total from Outlets		---	---	---
Total Carbon Fees from Outlets (Cost/hr)		---	---	---

----

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.	AQUEOUS PH.
Vapour / Phase Fraction	0.9929	0.9929	0.0071
Temperature: (F)	95.00	95.00	95.00
Pressure: (psia)	203.1	203.1	203.1
Molar Flow (lbmole/hr)	203.9	202.5	1.446
Mass Flow (lb/hr)	6492	6466	26.06
Std Ideal Liq VolFlow (barrel/day)	391.1	389.3	1.788
Molar Enthalpy (Btu/lbmole)	-1.257e+03	-3.898e+02	-1.227e+05
Molar Entropy (Btu/lbmole-F)	2.955e+01	2.966e+01	1.344e+01
Heat Flow (Btu/hr)	-2.564e+05	-7.892e+04	-1.775e+05
Liq VolFlow @Std Cond (barrel/day)	3.297e+005	3.274e+005	1.758

COMPOSITION

Overall Phase Vapour Fraction 0.9929

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

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	2.345	0.0115	42.24	0.0065	2.898	0.0074
Oxygen	201.6	0.9885	6450	0.9935	388.2	0.9926
Total	203.9	1.0000	6492	1.0000	391.1	1.0000

Vapour Phase Phase Fraction 0.9929

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

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	0.8986	0.0044	16.19	0.0025	1.111	0.0029
Oxygen	201.6	0.9956	6450	0.9975	388.2	0.9971
Total	202.5	1.0000	6466	1.0000	389.3	1.0000

Aqueous Phase Phase Fraction 7.094e-003

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

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	1.446	0.9999	26.06	0.9999	1.788	0.9999
Oxygen	7.424e-005	0.0001	2.376e-003	0.0001	1.430e-004	0.0001
Total	1.446	1.0000	26.06	1.0000	1.788	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
H2O	4.438e-003	---	4.438e-003
Oxygen	1.940e+004	---	1.940e+004

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Separator: V-100		

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.	AQUEOUS PH.
Vapour / Phase Fraction	1.0000	1.0000	0.0000
Temperature: (F)	123.2	123.2	123.2
Pressure: (psia)	203.1	203.1	203.1
Molar Flow (lbmole/hr)	203.6	203.6	0.0000
Mass Flow (lb/hr)	6487	6487	0.0000
Std Ideal Liq VolFlow (barrel/day)	390.7	390.7	0.0000
Molar Enthalpy (Btu/lbmole)	-7.664e+02	-7.664e+02	-1.222e+05
Molar Entropy (Btu/lbmole-F)	3.011e+01	3.011e+01	1.436e+01
Heat Flow (Btu/hr)	-1.560e+05	-1.560e+05	0.000e-01
Liq VolFlow @Std Cond (barrel/day)	3.292e+005	3.292e+005	0.0000

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	2.036	0.0100	36.68	0.0057	2.516	0.0064
Oxygen	201.6	0.9900	6450	0.9943	388.2	0.9936
Total	203.6	1.0000	6487	1.0000	390.7	1.0000

Vapour Phase Phase Fraction 1.000

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

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	2.036	0.0100	36.68	0.0057	2.516	0.0064
Oxygen	201.6	0.9900	6450	0.9943	388.2	0.9936
Total	203.6	1.0000	6487	1.0000	390.7	1.0000

Aqueous Phase Phase Fraction 0.0000

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

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	0.0000	0.9999	0.0000	0.9999	0.0000	0.9999
Oxygen	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
H2O	1.000e-002	---	1.000e-002
Oxygen	1.383e+004	---	1.383e+004

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Compressor: K-100	Separator: V-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.	AQUEOUS PH.
Vapour / Phase Fraction	0.0000	0.0000	1.0000
Temperature: (F)	123.2	123.2	123.2
Pressure: (psia)	203.1	203.1	203.1
Molar Flow (lbmole/hr)	0.3095	0.0000	0.3095
Mass Flow (lb/hr)	5.575	0.0000	5.575
Std Ideal Liq VolFlow (barrel/day)	0.3825	0.0000	0.3825
Molar Enthalpy (Btu/lbmole)	-1.222e+05	-7.661e+02	-1.222e+05
Molar Entropy (Btu/lbmole-F)	1.436e+01	3.011e+01	1.436e+01
Heat Flow (Btu/hr)	-3.781e+04	0.000e-01	-3.781e+04
Liq VolFlow @Std Cond (barrel/day)	0.3762	0.0000	0.3762

COMPOSITION

Overall Phase Vapour Fraction 0.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	0.3094	0.9999	5.575	0.9999	0.3825	0.9999
Oxygen	2.215e-005	0.0001	7.087e-004	0.0001	4.265e-005	0.0001
Total	0.3095	1.0000	5.575	1.0000	0.3825	1.0000

Vapour Phase Phase Fraction 0.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	0.0000	0.0100	0.0000	0.0057	0.0000	0.0064
Oxygen	0.0000	0.9900	0.0000	0.9943	0.0000	0.9936
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Aqueous Phase Phase Fraction 1.000

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

	(lbmole/hr)		(lb/hr)		(barrel/day)	
H2O	0.3094	0.9999	5.575	0.9999	0.3825	0.9999
Oxygen	2.215e-005	0.0001	7.087e-004	0.0001	4.265e-005	0.0001
Total	0.3095	1.0000	5.575	1.0000	0.3825	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
H2O	9.998e-003	---	9.998e-003
Oxygen	1.383e+004	---	1.383e+004

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
	Separator: V-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

----

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

----

Material Stream: 4 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	929.4	929.4
Pressure: (psia)	2901	2901

Molar Flow (lbmole/hr) 203.6 203.6
Mass Flow (lb/hr) 6487 6487
Std Ideal Liq VolFlow (barrel/day) 390.7 390.7
Molar Enthalpy (Btu/lbmole) 5.358e+03 5.358e+03
Molar Entropy (Btu/lbmole-F) 3.130e+01 3.130e+01
Heat Flow (Btu/hr) 1.091e+06 1.091e+06
Liq VolFlow @Std Cond (barrel/day) 3.292e+005 3.292e+005
COMPOSITION

Overall Phase Vapour Fraction 1.0000

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

	(lbmole/hr)		(lb/hr)		(barrel/day)	
H2O	2.036	0.0100	36.68	0.0057	2.516	0.0064
Oxygen	201.6	0.9900	6450	0.9943	388.2	0.9936
Total	203.6	1.0000	6487	1.0000	390.7	1.0000

Vapour Phase Phase Fraction 1.000

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

	(lbmole/hr)		(lb/hr)		(barrel/day)	
H2O	2.036	0.0100	36.68	0.0057	2.516	0.0064
Oxygen	201.6	0.9900	6450	0.9943	388.2	0.9936
Total	203.6	1.0000	6487	1.0000	390.7	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
H2O	---	---	---
Oxygen	---	---	---

UNIT OPERATIONS

FEED TO PRODUCT FROM LOGICAL CONNECTION

Cooler: E-100 Compressor: K-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.	AQUEOUS PH.
Vapour / Phase Fraction	0.9922	0.9922	0.0078
Temperature: (F)	122.0	122.0	122.0
Pressure: (psia)	2901	2901	2901
Molar Flow (lbmole/hr)	203.6	202.0	1.579
Mass Flow (lb/hr)	6487	6458	28.47
Std Ideal Liq VolFlow (barrel/day)	390.7	388.8	1.953
Molar Enthalpy (Btu/lbmole)	-1.428e+03	-4.852e+02	-1.220e+05
Molar Entropy (Btu/lbmole-F)	2.389e+01	2.396e+01	1.427e+01
Heat Flow (Btu/hr)	-2.906e+05	-9.801e+04	-1.926e+05
Liq VolFlow @Std Cond (barrel/day)	3.292e+005	3.267e+005	1.921

COMPOSITION

Overall Phase Vapour Fraction 0.9922

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	2.036	0.0100	36.68	0.0057	2.516	0.0064

Oxygen	201.6	0.9900	6450	0.9943	388.2	0.9936
Total	203.6	1.0000	6487	1.0000	390.7	1.0000

Vapour Phase Phase Fraction 0.9922

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	0.4579	0.0023	8.249	0.0013	0.5660	0.0015
Oxygen	201.6	0.9977	6450	0.9987	388.2	0.9985
Total	202.0	1.0000	6458	1.0000	388.8	1.0000

Aqueous Phase Phase Fraction 7.757e-003

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
H2O	1.578	0.9992	28.43	0.9986	1.950	0.9988
Oxygen	1.241e-003	0.0008	3.971e-002	0.0014	2.390e-003	0.0012
Total	1.579	1.0000	28.47	1.0000	1.953	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
H2O	2.269e-003	---	2.269e-003
Oxygen	1270	---	1270

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
	Cooler: E-100	

UTILITIES

(No utilities reference this stream)

PROCESS UTILITY

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

Separator: V-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
1	

Outlet Stream

Stream Name	To Unit Operation
2	Compressor: K-100
3	

Energy Stream

Stream Name	From Unit Operation
Q1	

PARAMETERS

Vessel Volume: 196.3 ft3 Level SP: 50.00 %   Liquid Volume: 98.17 ft3

Vessel Pressure: 203.1 psia Pressure Drop: 0.0000 psi Duty: 6.257e+004 Btu/hr

Heat Transfer Mode: Heating

User Variables

RATING

Sizing

Cylinder   Vertical   Separator has a Boot: No

Volume: 196.3 ft3   Diameter: 5.000 ft   Height: 10.00 ft

Nozzles

Base Elevation Relative to Ground Level 0.0000 ft Diameter 5.000 ft Height 10.00

	1	2	3
Diameter (ft)	0.5000	0.5000	0.5000
Elevation (Base) (ft)	5.000	10.00	0.0000
Elevation (Ground) (ft)	5.000	10.00	0.0000

Elevation (% of Height) (%) 50.00 100.00 0.00
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

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

Compressor: K-100

DESIGN
Connections
Inlet Stream

STREAM NAME	FROM UNIT OPERATION
2	V-100 Separator

Outlet Stream

STREAM NAME	TO UNIT OPERATION
4	E-100 Cooler

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Q2	

Parameters

Speed: --- Duty: 4.9003e+02 hp
Adiabatic Eff.: 75.00 PolyTropic Eff.: 81.45
Adiabatic Head: 1.122e+005 ft Polytropic Head: 1.218e+005 ft

Adiabatic Fluid Head: 1.122e+005 lbf-ft/lbm Polytropic Fluid Head: 1.218e+005 lbf-ft/lbm
Polytropic Exp. 1.531 Isentropic Exp. 1.414 Poly Head Factor 0.9957
User Variables

RATING

Curves

Compressor Speed: --- Efficiency: Adiabatic Curves Enabled: Yes
Head Offset: 0.0000 ft 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 103.5 ACFM Stone Wall Flow ---
Compressor Volume 0.0000 ft3
Nozzle Paramaters

Base Elevation Relative to Ground Level 0.0000 ft

	2	4
Diameter (ft)	0.1640	0.1640
Elevation (Base) (ft)	0.0000	0.0000
Elevation (Ground) (ft)	0.0000	0.0000

Inertia

Rotational inertia (lb-ft2) 142.4 Radius of gyration (ft) 0.6562
Mass (lb) 330.7 Friction loss factor (rad/min) (lb-ft2/s) 0.1424
PERFORMANCE

Results

Adiabatic Head (ft) 1.122e+005 Power Consumed (hp) 490.0
Polytropic Head (ft) 1.218e+005 Polytropic Head Factor 0.9957
Adiabatic Fluid Head (lbf-ft/lbm) 1.122e+005 Polytropic Exponent 1.531
Polytropic Fluid Head (lbf-ft/lbm) 1.218e+005 Isentropic Exponent 1.414
Adiabatic Efficiency 75 Speed (rpm) ---
Polytropic Efficiency 81 ---
Power/Torque

Total Rotor Power (hp) 490.0 Total Rotor Torque (lbf-ft) ---
Transient Rotor Power (hp) 0.0000 Transient Rotor Torque (lbf-ft) ---
Friction Power Loss (hp) 0.0000 Friction Torque Loss (lbf-ft) ---
Fluid Power (hp) 490.0 Fluid Torque (lbf-ft) ---

E-100 (Cooler): Design, Rating, Profiles, Tables

Cooler: E-100

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
4	K-100 Compressor

Outlet Stream

STREAM NAME	TO UNIT OPERATION
5	

Energy Stream

STREAM NAME TO UNIT OPERATION

Q3

PARAMETERS

Pressure Drop: 0.0000 psi Duty: 1.381e+006 Btu/hr Volume: 3.531 ft3

Function: Not Selected Zones: 1

User Variables

NOZZLE PARAMETERS

Base Elevation Relative to Ground Level 0.0000 ft

	4	5
Diameter (ft)	0.1640	0.1640
Elevation (Base) (ft)	0.0000	0.0000
Elevation (Ground) (ft)	0.0000	0.0000

PERFORMANCE PROFILES

Zone	Pressure (psia)	Temperature (F)	Vapour Fraction	Enthalpy (Btu/lbmole)
Inlet	2900.75	929.37	1.0000	5357.77
0	2900.75	122.00	0.9922	-1427.53

PERFORMANCE TABLE

Overall Phase

Temperature (F)	Pressure (psia)	Heat Flow (Btu/hr)	Enthalpy (Btu/lbmole)
929.37	2900.75	0.00	5357.77
848.64	2900.75	-135289.44	4693.27
767.90	2900.75	-269897.57	4032.12
687.16	2900.75	-403921.78	3373.83
606.42	2900.75	-537515.40	2717.66
525.69	2900.75	-670891.57	2062.56
444.95	2900.75	-804442.28	1406.60

364.21	2900.75	-938709.84	747.12
283.47	2900.75	-1074588.22	79.72
202.74	2900.75	-1213598.93	-603.05
122.00	2900.75	-1381457.76	-1427.53

Vapour Fraction	Vap Phase Mass Frac	Heat of Vap (Btu/lbmole)
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
1.0000	1.0000	---
0.9922	0.9956	---

Vapour Phase

Mass Flow (lb/hr)	Molecular Wt	Density (lb/ft3)	Mass Sp Heat (Btu/lb-F)	Viscosity (cP)	Thermal Cond (Btu/hr-ft-F)
6486.52	31.86	5.93	0.26	0.04	0.04
6486.52	31.86	6.29	0.26	0.04	0.03
6486.52	31.86	6.71	0.26	0.04	0.03
6486.52	31.86	7.19	0.26	0.04	0.03
6486.52	31.86	7.75	0.25	0.04	0.03
6486.52	31.86	8.41	0.25	0.04	0.03
6486.52	31.86	9.21	0.26	0.03	0.03
6486.52	31.86	10.21	0.26	0.03	0.03
6486.52	31.86	11.49	0.26	0.03	0.02
6486.52	31.86	13.20	0.27	0.03	0.02
6458.06	31.97	15.59	0.28	0.03	0.02

Std Gas Flow Z Factor Pseudo Pc Pseudo Tc Pseudo Zc Pseudo Omega

(MMSCFD)		(psia)	(F)		
1.85	1.05	761.51	-172.22	0.29	0.02
1.85	1.05	761.51	-172.22	0.29	0.02
1.85	1.05	761.51	-172.22	0.29	0.02
1.85	1.04	761.51	-172.22	0.29	0.02
1.85	1.04	761.51	-172.22	0.29	0.02
1.85	1.04	761.51	-172.22	0.29	0.02
1.85	1.03	761.51	-172.22	0.29	0.02
1.85	1.02	761.51	-172.22	0.29	0.02
1.85	1.01	761.51	-172.22	0.29	0.02
1.85	0.99	761.51	-172.22	0.29	0.02
1.84	0.95	742.40	-179.07	0.29	0.02

Light Liquid Phase

Mass Flow (lb/hr)	Density (lb/ft3)	Mass Sp Heat (Btu/lb-F)	Viscosity (cP)	Thermal Cond (Btu/hr-ft-F)	Surface Tens (dyne/cm)

Molecular Wt	Sp Gravity	Pseudo Pc (psia)	Pseudo Tc (F)	Pseudo Zc	Pseudo Omega

Heavy Liquid Phase

Mass Flow (lb/hr)	Density (lb/ft3)	Mass Sp Heat (Btu/lb-F)	Viscosity (cP)	Thermal Cond (Btu/hr-ft-F)	Surface Tens (dyne/cm)
28.47	62.10	1.02	0.54	0.37	67.68

Molecular Wt	Sp Gravity	Pseudo Pc (psia)	Pseudo Tc (F)	Pseudo Zc	Pseudo Omega
18.03	0.99	3206.29	704.77	0.26	0.34

Mixed Liquid Phase

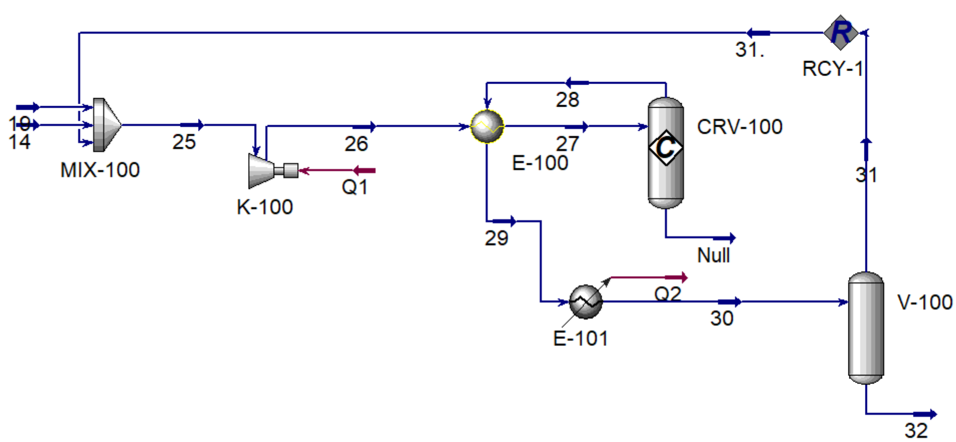
Mass Flow	Density	Mass Sp Heat	Viscosity	Thermal Cond	Surface Tens

(lb/hr)	(lb/ft3)	(Btu/lb-F)	(cP)	(Btu/hr-ft-F)	(dyne/cm)
28.47	62.10	1.02	0.54	0.37	67.68

Molecular Wt	Sp Gravity	Pseudo Pc (psia)	Pseudo Tc (F)	Pseudo Zc	Pseudo Omega
18.03	0.99	3206.29	704.77	0.26	0.34

Aspen Technology Inc. Aspen HYSYS Version 10

<u>Ammonia Unit</u>



INPUT SUMMARY

FLUID PACKAGE: Basis-1(Peng-Robinson)

Property Package Type: PengRob
Component List - 1: Hydrogen /Nitrogen /Ammonia /

Reaction Set: Set-1

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

Basis Data: Component = Nitrogen / Phase = Overall /

FLOWSHEET: Main

Fluid Package: Basis-1

STREAM: 19 (Material Stream)
Temperature = 104 F
Pressure = 203.05278 psia
Mass Flow = 899.4768 lb/hr
Composition Basis (In Mole Fractions):Hydrogen = 1/ Nitrogen = 0/ Ammonia = 0/

STREAM: 14 (Material Stream)
Temperature = 536 F
Pressure = 87.02262 psia
Mass Flow = 3777.03095 lb/hr
Composition Basis (In Mass Fractions):Hydrogen = 0/ Nitrogen = 1/ Ammonia = 0/

STREAM: 25 (Material Stream)

UNIT OPERATION: K-100 (Compressor)
Feed Stream = 25
Product Stream = 26
Energy Stream = Q1

STREAM: 26 (Material Stream)
Pressure = 870.2262 psia

STREAM: Q1 (Energy Stream)

UNIT OPERATION: E-100 (Heat Exchanger)
TubeInletStream = 26
TubeOutletStream = 27
ShellInletStream = 28
ShellOutletStream = 29
TubeOuterDiameter = 0.787401575 in

TubeInnerDiameter = 0.62992126 in
TubeThickness = FEMPTY in
HCurveName = 26-27
HCurveName = 28-29

STREAM: 27 (Material Stream)
Temperature = 995 F
Pressure = 870.2262 psia

STREAM: 28 (Material Stream)

STREAM: 29 (Material Stream)
Pressure = 870.2262 psia

UNIT OPERATION: CRV-100 (Conversion Reactor)
Feed Stream = 27
Vapour Product = 28
Liquid Product = Null
Reaction Set=Set-1
ReactionName = Rxn-1

STREAM: Q2 (Energy Stream)

UNIT OPERATION: E-101 (Cooler)
Feed Stream = 29
Product Stream = 30
Energy Stream = Q2

STREAM: 30 (Material Stream)
Temperature = -58 F
Pressure = 870.2262 psia

UNIT OPERATION: V-100 (Separator)
Feed Stream = 30
Vapour Product = 31
Liquid Product = 32

STREAM: 32 (Material Stream)

STREAM: 31 (Material Stream)

UNIT OPERATION: RCY-1 (Recycle)
Inlet Stream = 31

Output Stream = 31.

STREAM: 31. (Material Stream)
Temperature = -58 F
Pressure = 870.2262 psia
Molar Flow = 9340.08392 lbmole/hr
Composition Basis (In Mole Fractions):Hydrogen = 0.851958867/ Nitrogen = 0.138434697/ Ammonia = 0.00960643638/

OUTPUT SUMMARY

Case Name: ammonia fixed.hsc
Bedford, MA
USA Unit Set: Field

Date/Time: Wed Apr 01 14:53:07 2020

Basis-1 (Fluid Package): Component List

Fluid Package: Basis-1

COMPONENT LIST

Component List - 1 [HYSYS Databanks]

COMPONENT	TYPE	MOLECULAR WEIGHT	BOILING PT (F)	IDEAL LIQ DENSITY (lb/ft3)	CRITICAL TEMP (F)
Hydrogen	Pure	2.016	-422.7	4.361	-399.5
Nitrogen	Pure	28.01	-320.4	50.34	-232.5
Ammonia	Pure	17.03	-28.21	38.46	270.3

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

COMPONENT	CRITICAL PRES (psia)	CRITICAL VOL (ft3/lbmole)	ACENTRICITY	HEAT OF FORM (Btu/lbmole)
Hydrogen	190.8	0.8250	-0.1201	0.0000
Nitrogen	492.3	1.442	4.000e-002	0.0000
Ammonia	1636	1.288	0.2550	-1.965e+004

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

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Simulation Case: Case

OVERALL MASS BALANCE

In Stream	Count	Mass Flow (lb/hr)	Out Stream	Count	Mass Flow (lb/hr)
19	Yes	899.5	Null	Yes	0.0000
14	Yes	3777	32	Yes	4864

Total In MassFlow (lb/hr) 4677 Total Out MassFlow (lb/hr) 4864
Mass Imbalance (lb/hr) 187.7 Rel Mass Imbalance Pct (%) 4.01
OVERALL ENERGY BALANCE

InStream	Count	Energy Flow (Btu/hr)	OutStream	Count	Energy Flow (Btu/hr)
19	Yes	8.189e+04	Null	Yes	0.000e-01
14	Yes	4.403e+05	Q2	Yes	4.522e+07
Q1	Yes	3.577e+07	32	Yes	-8.920e+06

Total In EnergyFlow (Btu/hr) 3.629e+007 Total Out EnergyFlow (Btu/hr) 3.630e+007
Energy Imbalance (Btu/hr) 8380 Rel Energy Imbalance Pct (%) 0.02
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) (lb/hr)	IFPP (2007) (lb/hr)	EPA (2009) (lb/hr)
19	Yes	0.000e-01	0.000e-01	0.000e-01
14	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) (lb/hr)	IFPP (2007) (lb/hr)	EPA (2009) (lb/hr)
Null	Yes	0.000e-01	0.000e-01	0.000e-01

32	Yes	0.000e-01	0.000e-01	0.000e-01
Total from Outlets		---	---	---
Total Carbon Fees from Outlets (Cost/hr)		---	---	---

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19 (Material Stream): Worksheet, Attachments

Material Stream: 19 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	104.0	104.0
Pressure: (psia)	203.1	203.1
Molar Flow (lbmole/hr)	446.2	446.2
Mass Flow (lb/hr)	899.5	899.5
Std Ideal Liq VolFlow (barrel/day)	881.6	881.6
Molar Enthalpy (Btu/lbmole)	1.835e+02	1.835e+02
Molar Entropy (Btu/lbmole-F)	2.449e+01	2.449e+01
Heat Flow (Btu/hr)	8.189e+04	8.189e+04
Liq VolFlow @Std Cond (barrel/day)	7.226e+005	7.226e+005

PROPERTIES

	OVERALL	VAPOUR PH.
Molecular Weight	2.016	2.016
Molar Density (lbmole/ft3)	3.340e-002	3.340e-002
Mass Density (lb/ft3)	6.734e-002	6.734e-002
Act. Volume Flow (barrel/day)	5.710e+004	5.710e+004
Mass Enthalpy (Btu/lb)	91.04	91.04
Mass Entropy (Btu/lb-F)	12.15	12.15
Heat Capacity (Btu/lbmole-F)	6.819	6.819
Mass Heat Capacity (Btu/lb-F)	3.383	3.383
LHV Molar Basis (Std) (Btu/lbmole)	1.040e+005	1.040e+005
HHV Molar Basis (Std) (Btu/lbmole)	1.216e+005	1.216e+005
HHV Mass Basis (Std) (Btu/lb)	6.034e+004	6.034e+004
CO2 Loading	---	---
CO2 App ML Con (lbmole/ft3)	---	---
CO2 App WT Con (lbmol/lb)	---	---
LHV Mass Basis (Std) (Btu/lb)	5.160e+004	5.160e+004

Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy (Btu/lb)	1393	---
Partial Pressure of CO2 (psia)	0.0000	---
Cost Based on Flow (Cost/s)	0.0000	0.0000
Act. Gas Flow (ACFM)	222.6	222.6
Avg. Liq. Density (lbmole/ft3)	2.163	2.163
Specific Heat (Btu/lbmole-F)	6.819	6.819
Std. Gas Flow (MMSCFD)	4.056	4.056
Std. Ideal Liq. Mass Density (lb/ft3)	4.361	4.361
Act. Liq. Flow (USGPM)	---	---
Z Factor	1.005	1.005
Watson K	47.60	47.60
User Property	---	---
Partial Pressure of H2S (psia)	0.0000	---
Cp/(Cp - R)	1.411	1.411
Cp/Cv	1.416	1.416
Ideal Gas Cp/Cv	1.413	1.413
Ideal Gas Cp (Btu/lbmole-F)	6.797	6.797
Mass Ideal Gas Cp (Btu/lb-F)	3.371	3.371
Heat of Vap. (Btu/lbmole)	---	---
Kinematic Viscosity (cSt)	8.476	8.476
Liq. Mass Density (Std. Cond) (lb/ft3)	5.321e-003	5.321e-003
Liq. Vol. Flow (Std. Cond) (barrel/day)	7.226e+005	7.226e+005
Liquid Fraction	0.0000	0.0000
Molar Volume (ft3/lbmole)	29.94	29.94
Mass Heat of Vap. (Btu/lb)	---	---
Phase Fraction [Molar Basis]	1.0000	1.0000
Surface Tension (dyne/cm)	---	---
Thermal Conductivity (Btu/hr-ft-F)	0.1054	0.1054
Bubble Point Pressure (psia)	---	---
Viscosity (cP)	9.143e-003	9.143e-003
Cv (Semi-Ideal) (Btu/lbmole-F)	4.833	4.833
Mass Cv (Semi-Ideal) (Btu/lb-F)	2.398	2.398
Cv (Btu/lbmole-F)	4.816	4.816
Mass Cv (Btu/lb-F)	2.389	2.389
Cv (Ent. Method) (Btu/lbmole-F)	---	---
Mass Cv (Ent. Method) (Btu/lb-F)	---	---
Cp/Cv (Ent. Method)	---	---
Reid VP at 37.8 C (psia)	---	---
True VP at 37.8 C (psia)	---	---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day)	7.226e+005	7.226e+005

Viscosity Index 3.759 ---
COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	446.2	1.0000	899.5	1.0000	881.6	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
Total	446.2	1.0000	899.5	1.0000	881.6	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	446.2	1.0000	899.5	1.0000	881.6	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
Total	446.2	1.0000	899.5	1.0000	881.6	1.0000

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14 (Material Stream): Worksheet, Attachments

Material Stream: 14 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	536.0	536.0
Pressure: (psia)	87.02	87.02
Molar Flow (lbmole/hr)	134.8	134.8
Mass Flow (lb/hr)	3777	3777
Std Ideal Liq VolFlow (barrel/day)	320.7	320.7
Molar Enthalpy (Btu/lbmole)	3.266e+03	3.266e+03
Molar Entropy (Btu/lbmole-F)	3.622e+01	3.622e+01
Heat Flow (Btu/hr)	4.403e+05	4.403e+05
Liq VolFlow @Std Cond (barrel/day)	2.182e+005	2.182e+005

PROPERTIES

	OVERALL	VAPOUR PH.
Molecular Weight	28.01	28.01
Molar Density (lbmole/ft3)	8.128e-003	8.128e-003
Mass Density (lb/ft3)	0.2277	0.2277
Act. Volume Flow (barrel/day)	7.091e+004	7.091e+004
Mass Enthalpy (Btu/lb)	116.6	116.6
Mass Entropy (Btu/lb-F)	1.293	1.293
Heat Capacity (Btu/lbmole-F)	7.294	7.294
Mass Heat Capacity (Btu/lb-F)	0.2604	0.2604
LHV Molar Basis (Std) (Btu/lbmole)	0.0000	0.0000
HHV Molar Basis (Std) (Btu/lbmole)	0.0000	0.0000
HHV Mass Basis (Std) (Btu/lb)	0.0000	0.0000
CO2 Loading	---	---
CO2 App ML Con (lbmole/ft3)	---	---
CO2 App WT Con (lbmol/lb)	---	---
LHV Mass Basis (Std) (Btu/lb)	0.0000	0.0000
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy (Btu/lb)	100.3	---
Partial Pressure of CO2 (psia)	0.0000	---
Cost Based on Flow (Cost/s)	0.0000	0.0000
Act. Gas Flow (ACFM)	276.5	276.5
Avg. Liq. Density (lbmole/ft3)	1.797	1.797
Specific Heat (Btu/lbmole-F)	7.294	7.294
Std. Gas Flow (MMSCFD)	1.226	1.226
Std. Ideal Liq. Mass Density (lb/ft3)	50.34	50.34
Act. Liq. Flow (USGPM)	---	---
Z Factor	1.002	1.002
Watson K	6.415	6.415
User Property	---	---
Partial Pressure of H2S (psia)	0.0000	---
Cp/(Cp - R)	1.374	1.374
Cp/Cv	1.377	1.377
Ideal Gas Cp/Cv	1.375	1.375
Ideal Gas Cp (Btu/lbmole-F)	7.277	7.277
Mass Ideal Gas Cp (Btu/lb-F)	0.2598	0.2598
Heat of Vap. (Btu/lbmole)	2038	---
Kinematic Viscosity (cSt)	7.864	7.864
Liq. Mass Density (Std. Cond) (lb/ft3)	7.400e-002	7.400e-002
Liq. Vol. Flow (Std. Cond) (barrel/day)	2.182e+005	2.182e+005
Liquid Fraction	0.0000	0.0000
Molar Volume (ft3/lbmole)	123.0	123.0

Mass Heat of Vap. (Btu/lb) 72.73 ---
Phase Fraction [Molar Basis] 1.0000 1.0000
Surface Tension (dyne/cm) --- ---
Thermal Conductivity (Btu/hr-ft-F) 2.421e-002 2.421e-002
Bubble Point Pressure (psia) --- ---
Viscosity (cP) 2.868e-002 2.868e-002
Cv (Semi-Ideal) (Btu/lbmole-F) 5.309 5.309
Mass Cv (Semi-Ideal) (Btu/lb-F) 0.1895 0.1895
Cv (Btu/lbmole-F) 5.296 5.296
Mass Cv (Btu/lb-F) 0.1891 0.1891
Cv (Ent. Method) (Btu/lbmole-F) --- ---
Mass Cv (Ent. Method) (Btu/lb-F) --- ---
Cp/Cv (Ent. Method) --- ---
Reid VP at 37.8 C (psia) --- ---
True VP at 37.8 C (psia) --- ---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day) 2.182e+005 2.182e+005
Viscosity Index -7.429 ---
COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
Nitrogen 134.8 1.0000 3777 1.0000 320.7 1.0000
Ammonia 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
Total 134.8 1.0000 3777 1.0000 320.7 1.0000
Vapour Phase Phase Fraction 1.000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
Nitrogen 134.8 1.0000 3777 1.0000 320.7 1.0000
Ammonia 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
Total 134.8 1.0000 3777 1.0000 320.7 1.0000
----
25 (Material Stream): Worksheet, Attachments

Material Stream: 25 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	-48.14	-48.14
Pressure: (psia)	87.02	87.02
Molar Flow (lbmole/hr)	9921	9921
Mass Flow (lb/hr)	5.847e+004	5.847e+004
Std Ideal Liq VolFlow (barrel/day)	2.017e+004	2.017e+004
Molar Enthalpy (Btu/lbmole)	-1.035e+03	-1.035e+03
Molar Entropy (Btu/lbmole-F)	2.591e+01	2.591e+01
Heat Flow (Btu/hr)	-1.027e+07	-1.027e+07
Liq VolFlow @Std Cond (barrel/day)	1.607e+007	1.607e+007

PROPERTIES

	OVERALL	VAPOUR PH.
Molecular Weight	5.893	5.893
Molar Density (lbmole/ft3)	1.969e-002	1.969e-002
Mass Density (lb/ft3)	0.1161	0.1161
Act. Volume Flow (barrel/day)	2.154e+006	2.154e+006
Mass Enthalpy (Btu/lb)	-175.6	-175.6
Mass Entropy (Btu/lb-F)	4.397	4.397
Heat Capacity (Btu/lbmole-F)	6.815	6.815
Mass Heat Capacity (Btu/lb-F)	1.156	1.156
LHV Molar Basis (Std) (Btu/lbmole)	8.934e+004	8.934e+004
HHV Molar Basis (Std) (Btu/lbmole)	1.045e+005	1.045e+005
HHV Mass Basis (Std) (Btu/lb)	1.773e+004	1.773e+004
CO2 Loading	---	---
CO2 App ML Con (lbmole/ft3)	---	---
CO2 App WT Con (lbmol/lb)	---	---
LHV Mass Basis (Std) (Btu/lb)	1.516e+004	1.516e+004
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy (Btu/lb)	342.0	---
Partial Pressure of CO2 (psia)	0.0000	---
Cost Based on Flow (Cost/s)	0.0000	0.0000
Act. Gas Flow (ACFM)	8397	8397
Avg. Liq. Density (lbmole/ft3)	2.102	2.102
Specific Heat (Btu/lbmole-F)	6.815	6.815
Std. Gas Flow (MMSCFD)	90.18	90.18
Std. Ideal Liq. Mass Density (lb/ft3)	12.39	12.39
Act. Liq. Flow (USGPM)	---	---

Z Factor	1.001	1.001
Watson K	18.83	18.83
User Property	---	---
Partial Pressure of H_2S (psia)	0.0000	---
Cp/(Cp - R)	1.411	1.411
Cp/Cv	1.419	1.419
Ideal Gas Cp/Cv	1.414	1.414
Ideal Gas Cp (Btu/lbmole-F)	6.783	6.783
Mass Ideal Gas Cp (Btu/lb-F)	1.151	1.151
Heat of Vap. (Btu/lbmole)	2836	---
Kinematic Viscosity (cSt)	4.091	4.091
Liq. Mass Density (Std. Cond) (lb/ft3)	1.556e-002	1.556e-002
Liq. Vol. Flow (Std. Cond) (barrel/day)	1.607e+007	1.607e+007
Liquid Fraction	0.0000	0.0000
Molar Volume (ft3/lbmole)	50.78	50.78
Mass Heat of Vap. (Btu/lb)	481.2	---
Phase Fraction [Molar Basis]	1.0000	1.0000
Surface Tension (dyne/cm)	---	---
Thermal Conductivity (Btu/hr-ft-F)	6.081e-002	6.081e-002
Bubble Point Pressure (psia)	---	---
Viscosity (cP)	7.604e-003	7.604e-003
Cv (Semi-Ideal) (Btu/lbmole-F)	4.830	4.830
Mass Cv (Semi-Ideal) (Btu/lb-F)	0.8195	0.8195
Cv (Btu/lbmole-F)	4.802	4.802
Mass Cv (Btu/lb-F)	0.8149	0.8149
Cv (Ent. Method) (Btu/lbmole-F)	---	---
Mass Cv (Ent. Method) (Btu/lb-F)	---	---
Cp/Cv (Ent. Method)	---	---
Reid VP at 37.8 C (psia)	---	---
True VP at 37.8 C (psia)	---	---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day)	1.607e+007	1.607e+007
Viscosity Index	-13.53	---

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	8404	0.8470	1.694e+004	0.2898	1.661e+004	0.8232
Nitrogen	1428	0.1439	4.000e+004	0.6841	3396	0.1684
Ammonia	89.72	0.0090	1528	0.0261	169.8	0.0084
Total	9921	1.0000	5.847e+004	1.0000	2.017e+004	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	8404	0.8470	1.694e+004	0.2898	1.661e+004	0.8232
Nitrogen	1428	0.1439	4.000e+004	0.6841	3396	0.1684
Ammonia	89.72	0.0090	1528	0.0261	169.8	0.0084
Total	9921	1.0000	5.847e+004	1.0000	2.017e+004	1.0000

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26 (Material Stream): Worksheet, Attachments

Material Stream: 26 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	472.5	472.5
Pressure: (psia)	870.2	870.2
Molar Flow (lbmole/hr)	9921	9921
Mass Flow (lb/hr)	5.847e+004	5.847e+004
Std Ideal Liq VolFlow (barrel/day)	2.017e+004	2.017e+004
Molar Enthalpy (Btu/lbmole)	2.570e+03	2.570e+03
Molar Entropy (Btu/lbmole-F)	2.695e+01	2.695e+01
Heat Flow (Btu/hr)	2.550e+07	2.550e+07
Liq VolFlow @Std Cond (barrel/day)	1.607e+007	1.607e+007

PROPERTIES

	OVERALL	VAPOUR PH.
Molecular Weight	5.893	5.893
Molar Density (lbmole/ft3)	8.548e-002	8.548e-002
Mass Density (lb/ft3)	0.5037	0.5037
Act. Volume Flow (barrel/day)	4.961e+005	4.961e+005
Mass Enthalpy (Btu/lb)	436.1	436.1
Mass Entropy (Btu/lb-F)	4.573	4.573
Heat Capacity (Btu/lbmole-F)	7.043	7.043
Mass Heat Capacity (Btu/lb-F)	1.195	1.195
LHV Molar Basis (Std) (Btu/lbmole)	8.934e+004	8.934e+004
HHV Molar Basis (Std) (Btu/lbmole)	1.045e+005	1.045e+005
HHV Mass Basis (Std) (Btu/lb)	1.773e+004	1.773e+004
CO2 Loading	---	---

CO2 App ML Con (lbmole/ft3)	---	---
CO2 App WT Con (lbmol/lb)	---	---
LHV Mass Basis (Std) (Btu/lb)	1.516e+004	1.516e+004
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy (Btu/lb)	859.0	---
Partial Pressure of CO2 (psia)	0.0000	---
Cost Based on Flow (Cost/s)	0.0000	0.0000
Act. Gas Flow (ACFM)	1934	1934
Avg. Liq. Density (lbmole/ft3)	2.102	2.102
Specific Heat (Btu/lbmole-F)	7.043	7.043
Std. Gas Flow (MMSCFD)	90.18	90.18
Std. Ideal Liq. Mass Density (lb/ft3)	12.39	12.39
Act. Liq. Flow (USGPM)	---	---
Z Factor	1.018	1.018
Watson K	18.83	18.83
User Property	---	---
Partial Pressure of H2S (psia)	0.0000	---
Cp/(Cp - R)	1.393	1.393
Cp/Cv	1.402	1.402
Ideal Gas Cp/Cv	1.396	1.396
Ideal Gas Cp (Btu/lbmole-F)	6.995	6.995
Mass Ideal Gas Cp (Btu/lb-F)	1.187	1.187
Heat of Vap. (Btu/lbmole)	2891	---
Kinematic Viscosity (cSt)	1.907	1.907
Liq. Mass Density (Std. Cond) (lb/ft3)	1.556e-002	1.556e-002
Liq. Vol. Flow (Std. Cond) (barrel/day)	1.607e+007	1.607e+007
Liquid Fraction	0.0000	0.0000
Molar Volume (ft3/lbmole)	11.70	11.70
Mass Heat of Vap. (Btu/lb)	490.6	---
Phase Fraction [Molar Basis]	1.0000	1.0000
Surface Tension (dyne/cm)	---	---
Thermal Conductivity (Btu/hr-ft-F)	0.1149	0.1149
Bubble Point Pressure (psia)	---	---
Viscosity (cP)	1.539e-002	1.539e-002
Cv (Semi-Ideal) (Btu/lbmole-F)	5.057	5.057
Mass Cv (Semi-Ideal) (Btu/lb-F)	0.8581	0.8581
Cv (Btu/lbmole-F)	5.023	5.023
Mass Cv (Btu/lb-F)	0.8523	0.8523
Cv (Ent. Method) (Btu/lbmole-F)	---	---
Mass Cv (Ent. Method) (Btu/lb-F)	---	---
Cp/Cv (Ent. Method)	---	---

Reid VP at 37.8 C (psia) --- ---
True VP at 37.8 C (psia) --- ---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day) 1.607e+007 1.607e+007
Viscosity Index -11.08 ---
COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	8404	0.8470	1.694e+004	0.2898	1.661e+004	0.8232
Nitrogen	1428	0.1439	4.000e+004	0.6841	3396	0.1684
Ammonia	89.72	0.0090	1528	0.0261	169.8	0.0084
Total	9921	1.0000	5.847e+004	1.0000	2.017e+004	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	8404	0.8470	1.694e+004	0.2898	1.661e+004	0.8232
Nitrogen	1428	0.1439	4.000e+004	0.6841	3396	0.1684
Ammonia	89.72	0.0090	1528	0.0261	169.8	0.0084
Total	9921	1.0000	5.847e+004	1.0000	2.017e+004	1.0000

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27 (Material Stream): Worksheet, Attachments

Material Stream: 27 Fluid Package: Basis-1

Property Package: Peng-Robinson
CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	995.0	995.0
Pressure: (psia)	870.2	870.2
Molar Flow (lbmole/hr)	9921	9921
Mass Flow (lb/hr)	5.847e+004	5.847e+004
Std Ideal Liq VolFlow (barrel/day)	2.017e+004	2.017e+004
Molar Enthalpy (Btu/lbmole)	6.304e+03	6.304e+03
Molar Entropy (Btu/lbmole-F)	3.013e+01	3.013e+01
Heat Flow (Btu/hr)	6.254e+07	6.254e+07
Liq VolFlow @Std Cond (barrel/day)	1.607e+007	1.607e+007

PROPERTIES

	OVERALL	VAPOUR PH.
Molecular Weight	5.893	5.893
Molar Density (lbmole/ft3)	5.503e-002	5.503e-002
Mass Density (lb/ft3)	0.3243	0.3243
Act. Volume Flow (barrel/day)	7.707e+005	7.707e+005
Mass Enthalpy (Btu/lb)	1070	1070
Mass Entropy (Btu/lb-F)	5.112	5.112
Heat Capacity (Btu/lbmole-F)	7.258	7.258
Mass Heat Capacity (Btu/lb-F)	1.232	1.232
LHV Molar Basis (Std) (Btu/lbmole)	8.934e+004	8.934e+004
HHV Molar Basis (Std) (Btu/lbmole)	1.045e+005	1.045e+005
HHV Mass Basis (Std) (Btu/lb)	1.773e+004	1.773e+004
CO2 Loading	---	---
CO2 App ML Con (lbmole/ft3)	---	---
CO2 App WT Con (lbmol/lb)	---	---
LHV Mass Basis (Std) (Btu/lb)	1.516e+004	1.516e+004
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy (Btu/lb)	1203	---
Partial Pressure of CO2 (psia)	0.0000	---
Cost Based on Flow (Cost/s)	0.0000	0.0000
Act. Gas Flow (ACFM)	3005	3005
Avg. Liq. Density (lbmole/ft3)	2.102	2.102
Specific Heat (Btu/lbmole-F)	7.258	7.258
Std. Gas Flow (MMSCFD)	90.18	90.18
Std. Ideal Liq. Mass Density (lb/ft3)	12.39	12.39
Act. Liq. Flow (USGPM)	---	---
Z Factor	1.013	1.013
Watson K	18.83	18.83
User Property	---	---
Partial Pressure of H2S (psia)	0.0000	---
Cp/(Cp - R)	1.377	1.377
Cp/Cv	1.379	1.379
Ideal Gas Cp/Cv	1.378	1.378
Ideal Gas Cp (Btu/lbmole-F)	7.241	7.241
Mass Ideal Gas Cp (Btu/lb-F)	1.229	1.229
Heat of Vap. (Btu/lbmole)	2891	---
Kinematic Viscosity (cSt)	3.992	3.992
Liq. Mass Density (Std. Cond) (lb/ft3)	1.556e-002	1.556e-002
Liq. Vol. Flow (Std. Cond) (barrel/day)	1.607e+007	1.607e+007

Liquid Fraction 0.0000 0.0000
Molar Volume (ft3/lbmole) 18.17 18.17
Mass Heat of Vap. (Btu/lb) 490.6 ---
Phase Fraction [Molar Basis] 1.0000 1.0000
Surface Tension (dyne/cm) --- ---
Thermal Conductivity (Btu/hr-ft-F) 0.1559 0.1559
Bubble Point Pressure (psia) --- ---
Viscosity (cP) 2.074e-002 2.074e-002
Cv (Semi-Ideal) (Btu/lbmole-F) 5.272 5.272
Mass Cv (Semi-Ideal) (Btu/lb-F) 0.8946 0.8946
Cv (Btu/lbmole-F) 5.262 5.262
Mass Cv (Btu/lb-F) 0.8930 0.8930
Cv (Ent. Method) (Btu/lbmole-F) --- ---
Mass Cv (Ent. Method) (Btu/lb-F) --- ---
Cp/Cv (Ent. Method) --- ---
Reid VP at 37.8 C (psia) --- ---
True VP at 37.8 C (psia) --- ---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day) 1.607e+007 1.607e+007
Viscosity Index -2.799 ---
COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 8404 0.8470 1.694e+004 0.2898 1.661e+004 0.8232
Nitrogen 1428 0.1439 4.000e+004 0.6841 3396 0.1684
Ammonia 89.72 0.0090 1528 0.0261 169.8 0.0084
Total 9921 1.0000 5.847e+004 1.0000 2.017e+004 1.0000
Vapour Phase Phase Fraction 1.000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 8404 0.8470 1.694e+004 0.2898 1.661e+004 0.8232
Nitrogen 1428 0.1439 4.000e+004 0.6841 3396 0.1684
Ammonia 89.72 0.0090 1528 0.0261 169.8 0.0084
Total 9921 1.0000 5.847e+004 1.0000 2.017e+004 1.0000
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28 (Material Stream): Worksheet, Attachments

Material Stream: 28 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	1.0000	1.0000	0.0000
Temperature: (F)	1087	1087	1087
Pressure: (psia)	870.2	870.2	870.2
Molar Flow (lbmole/hr)	9636	9636	0.0000
Mass Flow (lb/hr)	5.847e+004	5.847e+004	0.0000
Std Ideal Liq VolFlow (barrel/day)	1.953e+004	1.953e+004	0.0000
Molar Enthalpy (Btu/lbmole)	6.490e+03	6.490e+03	6.490e+03
Molar Entropy (Btu/lbmole-F)	3.113e+01	3.113e+01	3.113e+01
Heat Flow (Btu/hr)	6.254e+07	6.254e+07	0.000e-01
Liq VolFlow @Std Cond (barrel/day)	1.560e+007	1.560e+007	0.0000

PROPERTIES

	OVERALL	VAPOUR PH.	LIQUID PH.
Molecular Weight	6.068	6.068	6.068
Molar Density (lbmole/ft3)	5.177e-002	5.177e-002	5.177e-002
Mass Density (lb/ft3)	0.3142	0.3142	0.3142
Act. Volume Flow (barrel/day)	7.955e+005	7.955e+005	0.0000
Mass Enthalpy (Btu/lb)	1070	1070	1069
Mass Entropy (Btu/lb-F)	5.130	5.130	5.129
Heat Capacity (Btu/lbmole-F)	7.459	7.459	7.459
Mass Heat Capacity (Btu/lb-F)	1.229	1.229	1.229
LHV Molar Basis (Std) (Btu/lbmole)	9.140e+004	9.140e+004	9.140e+004
HHV Molar Basis (Std) (Btu/lbmole)	1.070e+005	1.070e+005	1.070e+005
HHV Mass Basis (Std) (Btu/lb)	1.764e+004	1.764e+004	1.764e+004
CO2 Loading	---	---	---
CO2 App ML Con (lbmole/ft3)	---	---	---
CO2 App WT Con (lbmol/lb)	---	---	---
LHV Mass Basis (Std) (Btu/lb)	1.506e+004	1.506e+004	1.506e+004
Phase Fraction [Vol. Basis]	1.000	1.000	---
Phase Fraction [Mass Basis]	1.000	1.000	0.0000
Phase Fraction [Act. Vol. Basis]	1.000	1.000	0.0000
Mass Exergy (Btu/lb)	1248	---	---
Partial Pressure of CO2 (psia)	0.0000	---	---
Cost Based on Flow (Cost/s)	0.0000	0.0000	0.0000
Act. Gas Flow (ACFM)	3102	3102	---
Avg. Liq. Density (lbmole/ft3)	2.109	2.109	2.109
Specific Heat (Btu/lbmole-F)	7.459	7.459	7.459
Std. Gas Flow (MMSCFD)	87.59	87.59	0.0000

Std. Ideal Liq. Mass Density (lb/ft3)	12.80	12.80	12.80
Act. Liq. Flow (USGPM)	---	---	---
Z Factor	---	1.012	1.012
Watson K	19.05	19.05	19.05
User Property	---	---	---
Partial Pressure of H2S (psia)	0.0000	---	---
Cp/(Cp - R)	1.363	1.363	1.363
Cp/Cv	1.365	1.365	1.365
Ideal Gas Cp/Cv	1.364	1.364	1.364
Ideal Gas Cp (Btu/lbmole-F)	7.442	7.442	7.442
Mass Ideal Gas Cp (Btu/lb-F)	1.226	1.226	1.226
Heat of Vap. (Btu/lbmole)	3683	---	---
Kinematic Viscosity (cSt)	4.317	4.317	0.7052
Liq. Mass Density (Std. Cond) (lb/ft3)	1.602e-002	1.602e-002	1.602e-002
Liq. Vol. Flow (Std. Cond) (barrel/day)	1.560e+007	1.560e+007	0.0000
Liquid Fraction	0.0000	0.0000	1.000
Molar Volume (ft3/lbmole)	19.31	19.31	19.31
Mass Heat of Vap. (Btu/lb)	606.9	---	---
Phase Fraction [Molar Basis]	1.0000	1.0000	0.0000
Surface Tension (dyne/cm)	---	---	0.0000
Thermal Conductivity (Btu/hr-ft-F)	0.1598	0.1598	4.895e-002
Bubble Point Pressure (psia)	---	---	---
Viscosity (cP)	2.172e-002	2.172e-002	3.549e-003
Cv (Semi-Ideal) (Btu/lbmole-F)	5.473	5.473	5.473
Mass Cv (Semi-Ideal) (Btu/lb-F)	0.9020	0.9020	0.9019
Cv (Btu/lbmole-F)	5.463	5.463	5.463
Mass Cv (Btu/lb-F)	0.9003	0.9003	0.9003
Cv (Ent. Method) (Btu/lbmole-F)	---	---	---
Mass Cv (Ent. Method) (Btu/lb-F)	---	---	---
Cp/Cv (Ent. Method)	---	---	---
Reid VP at 37.8 C (psia)	---	---	---
True VP at 37.8 C (psia)	---	---	---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day)	1.560e+007	1.560e+007	0.0000
Viscosity Index	-2.022	---	---

COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	7975	0.8277	1.608e+004	0.2750	1.576e+004	0.8071
Nitrogen	1285	0.1334	3.600e+004	0.6157	3057	0.1565

Ammonia	375.3	0.0389	6391	0.1093	710.3	0.0364
Total	9636	1.0000	5.847e+004	1.0000	1.953e+004	1.0000

Vapour Phase Phase Fraction 1.000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	7975	0.8277	1.608e+004	0.2750	1.576e+004	0.8071
Nitrogen	1285	0.1334	3.600e+004	0.6157	3057	0.1565
Ammonia	375.3	0.0389	6391	0.1093	710.3	0.0364
Total	9636	1.0000	5.847e+004	1.0000	1.953e+004	1.0000

Liquid Phase Phase Fraction 0.0000

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	0.0000	0.8277	0.0000	0.2750	0.0000	0.8070
Nitrogen	0.0000	0.1334	0.0000	0.6157	0.0000	0.1566
Ammonia	0.0000	0.0390	0.0000	0.1094	0.0000	0.0364
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	1.000	1.000	---
Nitrogen	1.000	1.000	---
Ammonia	0.9992	0.9992	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Heat Exchanger: E-100	Conversion Reactor: CRV-100	

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29 (Material Stream): Worksheet, Attachments

Material Stream: 29 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	562.1	562.1
Pressure: (psia)	870.2	870.2

Molar Flow (lbmole/hr)	9636	9636
Mass Flow (lb/hr)	5.847e+004	5.847e+004
Std Ideal Liq VolFlow (barrel/day)	1.953e+004	1.953e+004
Molar Enthalpy (Btu/lbmole)	2.646e+03	2.646e+03
Molar Entropy (Btu/lbmole-F)	2.810e+01	2.810e+01
Heat Flow (Btu/hr)	2.550e+07	2.550e+07
Liq VolFlow @Std Cond (barrel/day)	1.560e+007	1.560e+007

PROPERTIES

	OVERALL	VAPOUR PH.
Molecular Weight	6.068	6.068
Molar Density (lbmole/ft3)	7.809e-002	7.809e-002
Mass Density (lb/ft3)	0.4738	0.4738
Act. Volume Flow (barrel/day)	5.275e+005	5.275e+005
Mass Enthalpy (Btu/lb)	436.1	436.1
Mass Entropy (Btu/lb-F)	4.630	4.630
Heat Capacity (Btu/lbmole-F)	7.182	7.182
Mass Heat Capacity (Btu/lb-F)	1.184	1.184
LHV Molar Basis (Std) (Btu/lbmole)	9.140e+004	9.140e+004
HHV Molar Basis (Std) (Btu/lbmole)	1.070e+005	1.070e+005
HHV Mass Basis (Std) (Btu/lb)	1.764e+004	1.764e+004
CO_2 Loading	---	---
CO_2 App ML Con (lbmole/ft3)	---	---
CO_2 App WT Con (lbmol/lb)	---	---
LHV Mass Basis (Std) (Btu/lb)	1.506e+004	1.506e+004
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy (Btu/lb)	882.6	---
Partial Pressure of CO_2 (psia)	0.0000	---
Cost Based on Flow (Cost/s)	0.0000	0.0000
Act. Gas Flow (ACFM)	2057	2057
Avg. Liq. Density (lbmole/ft3)	2.109	2.109
Specific Heat (Btu/lbmole-F)	7.182	7.182
Std. Gas Flow (MMSCFD)	87.59	87.59
Std. Ideal Liq. Mass Density (lb/ft3)	12.80	12.80
Act. Liq. Flow (USGPM)	---	---
Z Factor	1.016	1.016
Watson K	19.05	19.05
User Property	---	---
Partial Pressure of H_2S (psia)	0.0000	---
Cp/(Cp - R)	1.382	1.382
Cp/Cv	1.391	1.391
Ideal Gas Cp/Cv	1.386	1.386

Ideal Gas Cp (Btu/lbmole-F) 7.136 7.136
Mass Ideal Gas Cp (Btu/lb-F) 1.176 1.176
Heat of Vap. (Btu/lbmole) 3683 ---
Kinematic Viscosity (cSt) 2.156 2.156
Liq. Mass Density (Std. Cond) (lb/ft3) 1.602e-002 1.602e-002
Liq. Vol. Flow (Std. Cond) (barrel/day) 1.560e+007 1.560e+007
Liquid Fraction 0.0000 0.0000
Molar Volume (ft3/lbmole) 12.81 12.81
Mass Heat of Vap. (Btu/lb) 606.9 ---
Phase Fraction [Molar Basis] 1.0000 1.0000
Surface Tension (dyne/cm) --- ---
Thermal Conductivity (Btu/hr-ft-F) 0.1197 0.1197
Bubble Point Pressure (psia) --- ---
Viscosity (cP) 1.637e-002 1.637e-002
Cv (Semi-Ideal) (Btu/lbmole-F) 5.196 5.196
Mass Cv (Semi-Ideal) (Btu/lb-F) 0.8564 0.8564
Cv (Btu/lbmole-F) 5.163 5.163
Mass Cv (Btu/lb-F) 0.8509 0.8509
Cv (Ent. Method) (Btu/lbmole-F) --- ---
Mass Cv (Ent. Method) (Btu/lb-F) --- ---
Cp/Cv (Ent. Method) --- ---
Reid VP at 37.8 C (psia) --- ---
True VP at 37.8 C (psia) --- ---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day) 1.560e+007 1.560e+007
Viscosity Index -9.493 ---
COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 7975 0.8277 1.608e+004 0.2750 1.576e+004 0.8071
Nitrogen 1285 0.1334 3.600e+004 0.6157 3057 0.1565
Ammonia 375.3 0.0389 6391 0.1093 710.3 0.0364
Total 9636 1.0000 5.847e+004 1.0000 1.953e+004 1.0000
Vapour Phase Phase Fraction 1.000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 7975 0.8277 1.608e+004 0.2750 1.576e+004 0.8071
Nitrogen 1285 0.1334 3.600e+004 0.6157 3057 0.1565

Ammonia	375.3	0.0389	6391	0.1093	710.3	0.0364
Total	9636	1.0000	5.847e+004	1.0000	1.953e+004	1.0000

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30 (Material Stream): Worksheet, Attachments

Material Stream: 30 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	0.9703	0.9703	0.0297
Temperature: (F)	-58.00	-58.00	-58.00
Pressure: (psia)	870.2	870.2	870.2
Molar Flow (lbmole/hr)	9636	9349	286.0
Mass Flow (lb/hr)	5.847e+004	5.360e+004	4864
Std Ideal Liq VolFlow (barrel/day)	1.953e+004	1.898e+004	541.4
Molar Enthalpy (Btu/lbmole)	-2.046e+03	-1.155e+03	-3.119e+04
Molar Entropy (Btu/lbmole-F)	2.079e+01	2.100e+01	1.398e+01
Heat Flow (Btu/hr)	-1.972e+07	-1.080e+07	-8.920e+06
Liq VolFlow @Std Cond (barrel/day)	1.560e+007	1.514e+007	545.6

PROPERTIES

	OVERALL	VAPOUR PH.	LIQUID PH.
Molecular Weight	6.068	5.733	17.01
Molar Density (lbmole/ft3)	0.2053	0.1997	2.543
Mass Density (lb/ft3)	1.246	1.145	43.25
Act. Volume Flow (barrel/day)	2.006e+005	2.002e+005	480.8
Mass Enthalpy (Btu/lb)	-337.2	-201.4	-1834
Mass Entropy (Btu/lb-F)	3.427	3.663	0.8220
Heat Capacity (Btu/lbmole-F)	7.396	7.081	17.70
Mass Heat Capacity (Btu/lb-F)	1.219	1.235	1.041
LHV Molar Basis (Std) (Btu/lbmole)	9.140e+004	9.003e+004	1.361e+005
HHV Molar Basis (Std) (Btu/lbmole)	1.070e+005	1.053e+005	1.626e+005
HHV Mass Basis (Std) (Btu/lb)	1.764e+004	1.837e+004	9559
CO2 Loading	---	---	---
CO2 App ML Con (lbmole/ft3)	---	---	---
CO2 App WT Con (lbmol/lb)	---	---	---
LHV Mass Basis (Std) (Btu/lb)	1.506e+004	1.570e+004	8005
Phase Fraction [Vol. Basis]	0.9723	0.9723	2.773e-002
Phase Fraction [Mass Basis]	0.9168	0.9168	8.320e-002
Phase Fraction [Act. Vol. Basis]	0.9976	0.9976	2.396e-003

Mass Exergy (Btu/lb)	754.9	---	---
Partial Pressure of CO2 (psia)	0.0000	---	---
Cost Based on Flow (Cost/s)	0.0000	0.0000	0.0000
Act. Gas Flow (ACFM)	780.4	780.4	---
Avg. Liq. Density (lbmole/ft3)	2.109	2.105	2.258
Specific Heat (Btu/lbmole-F)	7.396	7.081	17.70
Std. Gas Flow (MMSCFD)	87.59	84.99	2.600
Std. Ideal Liq. Mass Density (lb/ft3)	12.80	12.07	38.40
Act. Liq. Flow (USGPM)	14.02	---	14.02
Z Factor	---	1.011	7.939e-002
Watson K	19.05	19.28	12.25
User Property	---	---	---
Partial Pressure of H2S (psia)	0.0000	---	---
Cp/(Cp - R)	1.367	1.390	1.126
Cp/Cv	1.415	1.461	2.184
Ideal Gas Cp/Cv	1.411	1.414	1.321
Ideal Gas Cp (Btu/lbmole-F)	6.821	6.780	8.166
Mass Ideal Gas Cp (Btu/lb-F)	1.124	1.183	0.4802
Heat of Vap. (Btu/lbmole)	3683	---	---
Kinematic Viscosity (cSt)	---	0.4180	0.4403
Liq. Mass Density (Std. Cond) (lb/ft3)	1.602e-002	1.513e-002	38.11
Liq. Vol. Flow (Std. Cond) (barrel/day)	1.560e+007	1.514e+007	545.6
Liquid Fraction	2.968e-002	0.0000	1.000
Molar Volume (ft3/lbmole)	4.871	5.008	0.3932
Mass Heat of Vap. (Btu/lb)	606.9	---	---
Phase Fraction [Molar Basis]	0.9703	0.9703	0.0297
Surface Tension (dyne/cm)	43.60	---	43.60
Thermal Conductivity (Btu/hr-ft-F)	---	6.234e-002	0.3761
Bubble Point Pressure (psia)	---	---	---
Viscosity (cP)	---	7.665e-003	0.3050
Cv (Semi-Ideal) (Btu/lbmole-F)	5.410	5.095	15.71
Mass Cv (Semi-Ideal) (Btu/lb-F)	0.8916	0.8886	0.9237
Cv (Btu/lbmole-F)	5.225	4.847	8.101
Mass Cv (Btu/lb-F)	0.8611	0.8454	0.4763
Cv (Ent. Method) (Btu/lbmole-F)	---	---	8.714
Mass Cv (Ent. Method) (Btu/lb-F)	---	---	0.5124
Cp/Cv (Ent. Method)	---	---	2.031
Reid VP at 37.8 C (psia)	---	---	216.7
True VP at 37.8 C (psia)	---	---	361.9
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day)	1.514e+007	1.514e+007	545.6
Viscosity Index	---	---	---

COMPOSITION

Overall Phase Vapour Fraction 0.9703

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	7975	0.8277	1.608e+004	0.2750	1.576e+004	0.8071
Nitrogen	1285	0.1334	3.600e+004	0.6157	3057	0.1565
Ammonia	375.3	0.0389	6391	0.1093	710.3	0.0364
Total	9636	1.0000	5.847e+004	1.0000	1.953e+004	1.0000

Vapour Phase Phase Fraction 0.9703

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	7975	0.8530	1.608e+004	0.2999	1.576e+004	0.8300
Nitrogen	1285	0.1374	3.600e+004	0.6715	3057	0.1610
Ammonia	89.79	0.0096	1529	0.0285	170.0	0.0090
Total	9349	1.0000	5.360e+004	1.0000	1.898e+004	1.0000

Liquid Phase Phase Fraction 2.968e-002

COMPONENTS	MOLE FLOW (lbmole/hr)	MOLE FRAC	MASS FLOW (lb/hr)	MASS FRAC	LIQVOL FLOW (barrel/day)	LIQVOL FRAC
Hydrogen	0.4824	0.0017	0.9725	0.0002	0.9532	0.0018
Nitrogen	4.599e-002	0.0002	1.288	0.0003	0.1094	0.0002
Ammonia	285.5	0.9982	4862	0.9995	540.4	0.9980
Total	286.0	1.0000	4864	1.0000	541.4	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	505.7	505.7	---
Nitrogen	854.7	854.7	---
Ammonia	9.622e-003	9.622e-003	---

UNIT OPERATIONS

FEED TO	PRODUCT FROM	LOGICAL CONNECTION
Separator: V-100	Cooler: E-101	

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32 (Material Stream): Worksheet, Attachments

Material Stream: 32 Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.	LIQUID PH.
Vapour / Phase Fraction	0.0000	0.0000	1.0000
Temperature: (F)	-58.00	-58.00	-58.00
Pressure: (psia)	870.2	870.2	870.2
Molar Flow (lbmole/hr)	286.0	0.0000	286.0
Mass Flow (lb/hr)	4864	0.0000	4864
Std Ideal Liq VolFlow (barrel/day)	541.4	0.0000	541.4
Molar Enthalpy (Btu/lbmole)	-3.119e+04	-1.155e+03	-3.119e+04
Molar Entropy (Btu/lbmole-F)	1.398e+01	2.100e+01	1.398e+01
Heat Flow (Btu/hr)	-8.920e+06	0.000e-01	-8.920e+06
Liq VolFlow @Std Cond (barrel/day)	545.6	0.0000	545.6

PROPERTIES

	OVERALL	VAPOUR PH.	LIQUID PH.
Molecular Weight	17.01	5.733	17.01
Molar Density (lbmole/ft3)	2.543	0.1997	2.543
Mass Density (lb/ft3)	43.25	1.145	43.25
Act. Volume Flow (barrel/day)	480.8	0.0000	480.8
Mass Enthalpy (Btu/lb)	-1834	-201.4	-1834
Mass Entropy (Btu/lb-F)	0.8220	3.663	0.8220
Heat Capacity (Btu/lbmole-F)	17.70	7.081	17.70
Mass Heat Capacity (Btu/lb-F)	1.041	1.235	1.041
LHV Molar Basis (Std) (Btu/lbmole)	1.361e+005	9.003e+004	1.361e+005
HHV Molar Basis (Std) (Btu/lbmole)	1.626e+005	1.053e+005	1.626e+005
HHV Mass Basis (Std) (Btu/lb)	9559	1.837e+004	9559
LHV Mass Basis (Std) (Btu/lb)	8005	1.570e+004	8005
Phase Fraction [Vol. Basis]	---	---	1.000
Phase Fraction [Mass Basis]	0.0000	0.0000	1.000
Phase Fraction [Act. Vol. Basis]	0.0000	0.0000	1.000
Mass Exergy (Btu/lb)	165.0	---	---
Partial Pressure of CO2 (psia)	0.0000	---	---
Cost Based on Flow (Cost/s)	0.0000	0.0000	0.0000
Act. Gas Flow (ACFM)	---	---	---
Avg. Liq. Density (lbmole/ft3)	2.258	2.105	2.258
Specific Heat (Btu/lbmole-F)	17.70	7.081	17.70
Std. Gas Flow (MMSCFD)	2.600	0.0000	2.600
Std. Ideal Liq. Mass Density (lb/ft3)	38.40	12.07	38.40
Act. Liq. Flow (USGPM)	14.02	---	14.02
Z Factor	---	1.011	7.939e-002
Watson K	12.25	19.28	12.25
User Property	---	---	---

Partial Pressure of H2S (psia) 0.0000 --- ---
Cp/(Cp - R) 1.126 1.390 1.126
Cp/Cv 2.184 1.461 2.184
Ideal Gas Cp/Cv 1.321 1.414 1.321
Ideal Gas Cp (Btu/lbmole-F) 8.166 6.780 8.166
Mass Ideal Gas Cp (Btu/lb-F) 0.4802 1.183 0.4802
Heat of Vap. (Btu/lbmole) 5772 --- ---
Kinematic Viscosity (cSt) 0.4403 0.4180 0.4403
Liq. Mass Density (Std. Cond) (lb/ft3) 38.11 1.513e-002 38.11
Liq. Vol. Flow (Std. Cond) (barrel/day) 545.6 0.0000 545.6
Liquid Fraction 1.000 0.0000 1.000
Molar Volume (ft3/lbmole) 0.3932 5.008 0.3932
Mass Heat of Vap. (Btu/lb) 339.4 --- ---
Phase Fraction [Molar Basis] 0.0000 0.0000 1.0000
Surface Tension (dyne/cm) 43.60 --- 43.60
Thermal Conductivity (Btu/hr-ft-F) 0.3761 6.234e-002 0.3761
Bubble Point Pressure (psia) 869.7 --- ---
Viscosity (cP) 0.3050 7.665e-003 0.3050
Cv (Semi-Ideal) (Btu/lbmole-F) 15.71 5.095 15.71
Mass Cv (Semi-Ideal) (Btu/lb-F) 0.9237 0.8886 0.9237
Cv (Btu/lbmole-F) 8.101 4.847 8.101
Mass Cv (Btu/lb-F) 0.4763 0.8454 0.4763
Cv (Ent. Method) (Btu/lbmole-F) 8.714 --- 8.714
Mass Cv (Ent. Method) (Btu/lb-F) 0.5124 --- 0.5124
Cp/Cv (Ent. Method) 2.031 --- 2.031
Reid VP at 37.8 C (psia) 216.7 --- 216.7
True VP at 37.8 C (psia) 361.9 --- 361.9
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day) 545.6 0.0000 545.6
Viscosity Index -11.35 --- ---
COMPOSITION
Overall Phase Vapour Fraction 0.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 0.4824 0.0017 0.9725 0.0002 0.9532 0.0018
Nitrogen 4.599e-002 0.0002 1.288 0.0003 0.1094 0.0002
Ammonia 285.5 0.9982 4862 0.9995 540.4 0.9980
Total 286.0 1.0000 4864 1.0000 541.4 1.0000
Vapour Phase Phase Fraction 0.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC (lbmole/hr) (lb/hr) (barrel/day)

Hydrogen	0.0000	0.8530	0.0000	0.2999	0.0000	0.8300
Nitrogen	0.0000	0.1374	0.0000	0.6715	0.0000	0.1610
Ammonia	0.0000	0.0096	0.0000	0.0285	0.0000	0.0090
Total	0.0000	1.0000	0.0000	1.0000	0.0000	1.0000

Liquid Phase Phase Fraction 1.000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)

Hydrogen	0.4824	0.0017	0.9725	0.0002	0.9532	0.0018
Nitrogen	4.599e-002	0.0002	1.288	0.0003	0.1094	0.0002
Ammonia	285.5	0.9982	4862	0.9995	540.4	0.9980
Total	286.0	1.0000	4864	1.0000	541.4	1.0000

K VALUE

COMPONENTS	MIXED	LIGHT	HEAVY
Hydrogen	505.7	505.7	---
Nitrogen	854.7	854.7	---
Ammonia	9.622e-003	9.622e-003	---

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31. (Material Stream): Worksheet, Attachments

Material Stream: 31. Fluid Package: Basis-1

Property Package: Peng-Robinson

CONDITIONS

	OVERALL	VAPOUR PH.
Vapour / Phase Fraction	1.0000	1.0000
Temperature: (F)	-58.00	-58.00
Pressure: (psia)	870.2	870.2
Molar Flow (lbmole/hr)	9340	9340
Mass Flow (lb/hr)	5.379e+004	5.379e+004
Std Ideal Liq VolFlow (barrel/day)	1.897e+004	1.897e+004
Molar Enthalpy (Btu/lbmole)	-1.155e+03	-1.155e+03
Molar Entropy (Btu/lbmole-F)	2.101e+01	2.101e+01
Heat Flow (Btu/hr)	-1.079e+07	-1.079e+07
Liq VolFlow @Std Cond (barrel/day)	1.513e+007	1.513e+007

PROPERTIES

OVERALL VAPOUR PH.

Molecular Weight	5.759	5.759
Molar Density (lbmole/ft3)	0.1997	0.1997
Mass Density (lb/ft3)	1.150	1.150
Act. Volume Flow (barrel/day)	1.999e+005	1.999e+005
Mass Enthalpy (Btu/lb)	-200.5	-200.5
Mass Entropy (Btu/lb-F)	3.648	3.648
Heat Capacity (Btu/lbmole-F)	7.082	7.082
Mass Heat Capacity (Btu/lb-F)	1.230	1.230
LHV Molar Basis (Std) (Btu/lbmole)	8.993e+004	8.993e+004
HHV Molar Basis (Std) (Btu/lbmole)	1.052e+005	1.052e+005
HHV Mass Basis (Std) (Btu/lb)	1.827e+004	1.827e+004
CO2 Loading	---	---
CO2 App ML Con (lbmole/ft3)	---	---
CO2 App WT Con (lbmol/lb)	---	---
LHV Mass Basis (Std) (Btu/lb)	1.561e+004	1.561e+004
Phase Fraction [Vol. Basis]	1.000	1.000
Phase Fraction [Mass Basis]	1.000	1.000
Phase Fraction [Act. Vol. Basis]	1.000	1.000
Mass Exergy (Btu/lb)	783.6	---
Partial Pressure of CO2 (psia)	0.0000	---
Cost Based on Flow (Cost/s)	0.0000	0.0000
Act. Gas Flow (ACFM)	779.6	779.6
Avg. Liq. Density (lbmole/ft3)	2.105	2.105
Specific Heat (Btu/lbmole-F)	7.082	7.082
Std. Gas Flow (MMSCFD)	84.90	84.90
Std. Ideal Liq. Mass Density (lb/ft3)	12.12	12.12
Act. Liq. Flow (USGPM)	---	---
Z Factor	1.011	1.011
Watson K	19.21	19.21
User Property	---	---
Partial Pressure of H2S (psia)	0.0000	---
Cp/(Cp - R)	1.390	1.390
Cp/Cv	1.461	1.461
Ideal Gas Cp/Cv	1.414	1.414
Ideal Gas Cp (Btu/lbmole-F)	6.780	6.780
Mass Ideal Gas Cp (Btu/lb-F)	1.177	1.177
Heat of Vap. (Btu/lbmole)	2875	---
Kinematic Viscosity (cSt)	0.4166	0.4166
Liq. Mass Density (Std. Cond) (lb/ft3)	1.520e-002	1.520e-002
Liq. Vol. Flow (Std. Cond) (barrel/day)	1.513e+007	1.513e+007
Liquid Fraction	0.0000	0.0000
Molar Volume (ft3/lbmole)	5.008	5.008
Mass Heat of Vap. (Btu/lb)	499.2	---

Phase Fraction [Molar Basis] 1.0000 1.0000
Surface Tension (dyne/cm) --- ---
Thermal Conductivity (Btu/hr-ft-F) 6.223e-002 6.223e-002
Bubble Point Pressure (psia) --- ---
Viscosity (cP) 7.674e-003 7.674e-003
Cv (Semi-Ideal) (Btu/lbmole-F) 5.096 5.096
Mass Cv (Semi-Ideal) (Btu/lb-F) 0.8848 0.8848
Cv (Btu/lbmole-F) 4.847 4.847
Mass Cv (Btu/lb-F) 0.8417 0.8417
Cv (Ent. Method) (Btu/lbmole-F) --- ---
Mass Cv (Ent. Method) (Btu/lb-F) --- ---
Cp/Cv (Ent. Method) --- ---
Reid VP at 37.8 C (psia) --- ---
True VP at 37.8 C (psia) --- ---
Liq. Vol. Flow - Sum(Std. Cond) (barrel/day) 1.513e+007 1.513e+007
Viscosity Index --- ---
COMPOSITION

Overall Phase Vapour Fraction 1.0000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 7957 0.8520 1.604e+004 0.2982 1.572e+004 0.8289
Nitrogen 1293 0.1384 3.622e+004 0.6734 3076 0.1621
Ammonia 89.72 0.0096 1528 0.0284 169.8 0.0090
Total 9340 1.0000 5.379e+004 1.0000 1.897e+004 1.0000
Vapour Phase Phase Fraction 1.000

COMPONENTS MOLE FLOW MOLE FRAC MASS FLOW MASS FRAC LIQVOL FLOW LIQVOL FRAC
(lbmole/hr) (lb/hr) (barrel/day)
Hydrogen 7957 0.8520 1.604e+004 0.2982 1.572e+004 0.8289
Nitrogen 1293 0.1384 3.622e+004 0.6734 3076 0.1621
Ammonia 89.72 0.0096 1528 0.0284 169.8 0.0090
Total 9340 1.0000 5.379e+004 1.0000 1.897e+004 1.0000

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

Compressor: K-100
DESIGN

Connections

Inlet Stream

STREAM NAME	TO UNIT OPERATION
26	E-100 Heat Exchanger

Energy Stream

STREAM NAME	FROM UNIT OPERATION
Q1	

Parameters

Speed: --- Duty: 1.4056e+04 hp
Adiabatic Eff.: 75.00 PolyTropic Eff.: 81.47
Adiabatic Head: 3.570e+005 ft Polytropic Head: 3.878e+005 ft
Adiabatic Fluid Head: 3.570e+005 lbf-ft/lbm Polytropic Fluid Head: 3.878e+005 lbf-ft/lbm
Polytropic Exp. 1.569 Isentropic Exp. 1.426 Poly Head Factor 0.9983
User Variables

RATING

Curves

Compressor Speed: --- Efficiency: Adiabatic Curves Enabled: Yes
Head Offset: 0.0000 ft 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 8397 ACFM Stone Wall Flow --- Compressor Volume 0.0000 ft3

Base Elevation Relative to Ground Level 0.0000 ft

	25	26
Diameter (ft)	0.1640	0.1640
Elevation (Base) (ft)	0.0000	0.0000
Elevation (Ground) (ft)	0.0000	0.0000

Inertia

Rotational inertia (lb-ft2) 142.4 Radius of gyration (ft) 0.6562
Mass (lb) 330.7 Friction loss factor (rad/min) (lb-ft2/s) 0.1424
PERFORMANCE

Results

Adiabatic Head (ft) 3.570e+005 Power Consumed (hp) 1.406e+004
Polytropic Head (ft) 3.878e+005 Polytropic Head Factor 0.9983
Adiabatic Fluid Head (lbf-ft/lbm) 3.570e+005 Polytropic Exponent 1.569
Polytropic Fluid Head (lbf-ft/lbm) 3.878e+005 Isentropic Exponent 1.426
Adiabatic Efficiency 75 Speed (rpm) ---
Polytropic Efficiency 81 ---
Power/Torque

Total Rotor Power (hp) 1.406e+004 Total Rotor Torque (lbf-ft) ---
Transient Rotor Power (hp) 0.0000 Transient Rotor Torque (lbf-ft) ---
Friction Power Loss (hp) 0.0000 Friction Torque Loss (lbf-ft) ---
Fluid Power (hp) 1.406e+004 Fluid Torque (lbf-ft) ---

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 26 Name 27 Name 28 Name 29
From Op. K-100 To Op. CRV-100 From Op. CRV-100 To Op. E-101
Op. Type Compressor Op. Type Conversion Reactor Op. Type Conversion Reactor Op. Type Cooler
Temp 472.46 F Temp 995.00 F Temp 1087.45 F Temp 562.08 F
PARAMETERS

Heat Exchanger Model: Simple End Point

Tube Side DeltaP: 0.0000 psi Shell Side DeltaP: 0.0000 psi Passes: ---
UA: 2.034e+006 Btu/F-hr Tolerance: 1.0000e-04
Tube Side Data Shell Side Data
Heat Transfer Coeff --- Heat Transfer Coeff ---

Tube Pressure Drop	0.00 psi	Shell Pressure Drop	0.00 psi
Fouling	0.00000 F-hr-ft2/Btu	Fouling	0.00000 F-hr-ft2/Btu
Tube Length	19.69 ft	Shell Passes	1
Tube O.D.	0.79 in	Shell Series	1
Tube Thickness	0.0787 in	Shell Parallel	1
Tube Pitch	1.9685 in	Baffle Type	Single
Orientation	Horizontal	Baffle Cut(%Area)	20.00
Passes Per Shell	2	Baffle Orientation	Horizontal
Tubes Per Shell	160	Spacing	31.4961 in
Layout Angle	Triangular (30 degrees)	Diameter	29.0964 in
TEMA Type	A E L	Area	649.26 ft2

SPECS

	Spec Value	Curr Value	Rel Error	Active	Estimate
E-100 Heat Balance	0.0000 Btu/hr	6.207e-009 Btu/hr	1.676e-016	On	Off
E-100 UA	---	2.034e+006 Btu/F-hr	---	On	Off

Detailed Specifications

E-100 Heat Balance

Type: Duty Pass: Error Spec Value: 0.0000 Btu/hr

E-100 UA

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

User Variables

DETAILS

Overall/Detailed Performance

Duty: 3.704e+07 Btu/hr	UA Curv. Error: 0.00e-01 Btu/F-hr
Heat Leak: 0.000e-01 Btu/hr	Hot Pinch Temp: 562.1 F
Heat Loss: 0.000e-01 Btu/hr	Cold Pinch Temp: 472.5 F
UA: 2.034e+06 Btu/F-hr	Ft Factor: ---
Min. Approach: 89.62 F	Uncorrected Lmtd: 91.03 F
Lmtd: 18.21 F	

TABLES

Shell Side - Overall Phase

Temperature (F)	Pressure (psia)	Heat Flow (Btu/hr)	Enthalpy (Btu/lbmole)
562.08	870.23	0.00	2646.43
1087.45	870.23	37039062.08	6490.40

UA	Molar Vap Frac	Mass Vap Frac	Heat of Vap.

(Btu/F-hr) (Btu/lbmole)
0.00 1.0000 1.0000 ---
0.00 1.0000 1.0000 ---
Shell Side - Vapour Phase

Mass Flow Molecular Wt Density Mass Sp Heat Viscosity Thermal Cond
(lb/hr) (lb/ft3) (Btu/lb-F) (cP) (Btu/hr-ft-F)
58467.01 6.07 0.47 1.18 0.02 0.12
58467.01 6.07 0.31 1.23 0.02 0.16
Std Gas Flow Z Factor Pseudo Pc Pseudo Tc Pseudo Zc Pseudo Omega
(MMSCFD) (psia) (F)
87.59 1.02 287.28 -351.12 0.30 -0.08
87.59 1.01 287.28 -351.12 0.30 -0.08
Shell Side - Light Liquid Phase

Mass Flow Density Mass Sp Heat Viscosity Thermal Cond Surface Tens
(lb/hr) (lb/ft3) (Btu/lb-F) (cP) (Btu/hr-ft-F) (dyne/cm)
--- --- --- --- --- ---
0.00 0.31 1.23 0.00 0.05 0.00
Molecular Wt Sp Gravity Pseudo Pc Pseudo Tc Pseudo Zc Pseudo Omega
(psia) (F)
--- --- --- --- --- ---
6.07 0.01 287.32 -351.10 0.30 -0.08
Shell Side - Heavy Liquid Phase
Mass Flow Density Mass Sp Heat Viscosity Thermal Cond Surface Tens
(lb/hr) (lb/ft3) (Btu/lb-F) (cP) (Btu/hr-ft-F) (dyne/cm)
--- --- --- --- --- ---
0.00 0.31 1.23 0.00 0.05 ---
Molecular Wt Sp Gravity Pseudo Pc Pseudo Tc Pseudo Zc Pseudo Omega
(psia) (F)
--- --- --- --- --- ---
6.07 0.01 287.32 -351.10 0.30 -0.08
Tube Side - Overall Phase

Temperature Pressure Heat Flow Enthalpy
(F) (psia) (Btu/hr) (Btu/lbmole)
472.46 870.23 0.00 2570.26
995.00 870.23 37039062.08 6303.59
UA Molar Vap Frac Mass Vap Frac Heat of Vap.
(Btu/F-hr) (Btu/lbmole)
0.00 1.0000 1.0000 ---
0.00 1.0000 1.0000 ---
Tube Side - Vapour Phase

Mass Flow (lb/hr)	Molecular Wt	Density (lb/ft3)	Mass Sp Heat (Btu/lb-F)	Viscosity (cP)	Thermal Cond (Btu/hr-ft-F)
58467.15	5.89	0.50	1.20	0.02	0.11
58467.15	5.89	0.32	1.23	0.02	0.16

Std Gas Flow (MMSCFD)	Z Factor	Pseudo Pc (psia)	Pseudo Tc (F)	Pseudo Zc	Pseudo Omega
90.18	1.02	247.26	-369.39	0.30	-0.09
90.18	1.01	247.26	-369.39	0.30	-0.09

CRV-100 (Conversion Reactor): Design, Reactions, Rating

Conversion Reactor: CRV-100

CONNECTIONS

Inlet Stream Connections

Stream Name	From Unit Operation
27	E-100 Heat Exchanger

Outlet Stream Connections

Stream Name	To Unit Operation
28	Heat Exchanger: E-100
Null	

Energy Stream Connections

Stream Name	From Unit Operation

Reaction: Rxn-1

Component	Mole Weight	Stoichiometric Coeff.
Nitrogen	28.01	-1.000
Hydrogen	2.016	-3.000
Ammonia	17.03	2.000

REACTION RESULTS FOR : Set-1

Extents

Name	Rank	Specified % Conversion	Use Default	Actual % Conversion	Base Component	Reaction Extent
Rxn-1	0	10.00	Yes	10.00	Nitrogen	1.799e-002

Balance

Components	Total Inflow	Total Reaction	Total Outflow
Hydrogen	1.059	-5.397e-002	1.005
Nitrogen	0.1799	-1.799e-002	0.1619
Ammonia	1.131e-002	3.598e-002	4.729e-002

RATING

E-101 (Cooler): Design, Rating, Profiles, Tables

Cooler: E-101

CONNECTIONS

Inlet Stream

STREAM NAME	FROM UNIT OPERATION
29	E-100 Heat Exchanger

Outlet Stream

STREAM NAME	TO UNIT OPERATION
30	V-100 Separator

Energy Stream

STREAM NAME	TO UNIT OPERATION
Q2	

PARAMETERS

Pressure Drop: 0.0000 psi Duty: 4.522e+007 Btu/hr Volume: 3.531 ft3

Function: Not Selected   Zones: 1

User Variables

PERFORMANCE TABLE

Overall Phase

Temperature (F)	Pressure (psia)	Heat Flow (Btu/hr)	Enthalpy (Btu/lbmole)
562.08	870.23	0.00	2646.43
500.07	870.23	-4282174.75	2202.02
438.06	870.23	-8548077.34	1759.30
376.05	870.23	-12799139.22	1318.11
314.05	870.23	-17037229.18	878.28

252.04	870.23	-21264822.65	439.53
190.03	870.23	-25485269.65	1.53
128.02	870.23	-29703239.57	-436.22
66.02	870.23	-33925502.45	-874.41
4.01	870.23	-38162401.89	-1314.13
-58.00	870.23	-45216132.64	-2046.17

Vapour Fraction Vap Phase Mass Frac Heat of Vap

Mass Flow (lb/hr)	Molecular Wt	Density (lb/ft3)	Mass Sp Heat (Btu/lb-F)	Viscosity (cP)	Thermal Cond (Btu/hr-ft-F)
58467.01	6.07	0.47	1.18	0.02	0.12
58467.01	6.07	0.50	1.18	0.02	0.11
58467.01	6.07	0.54	1.17	0.01	0.11
58467.01	6.07	0.58	1.17	0.01	0.10
58467.01	6.07	0.62	1.17	0.01	0.10
58467.01	6.07	0.68	1.17	0.01	0.09
58467.01	6.07	0.74	1.16	0.01	0.09
58467.01	6.07	0.82	1.16	0.01	0.08
58467.01	6.07	0.92	1.17	0.01	0.07
58467.01	6.07	1.05	1.17	0.01	0.07
53602.76	5.73	1.14	1.24	0.01	0.06

Std Gas Flow (MMSCFD)	Z Factor	Pseudo Pc (psia)	Pseudo Tc (F)	Pseudo Zc	Pseudo Omega
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.02	287.28	-351.12	0.30	-0.08
87.59	1.01	287.28	-351.12	0.30	-0.08
87.59	1.01	287.28	-351.12	0.30	-0.08
84.99	1.01	246.11	-370.10	0.30	-0.09

Light Liquid Phase

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

Separator: V-100

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
30	Cooler: E-101

Outlet Stream

Stream Name	To Unit Operation
31	Recycle: RCY-1
32	

Energy Stream

RCY-1 (Recycle): Design

Recycle: RCY-1

CONNECTIONS

Inlet Stream

Stream Name	From Unit Operation
31	V-100 Separator

Outlet Stream

Stream Name	To Unit Operation
31.	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

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