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# Alternative Technology for Sour Water Stripping

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Sour water is a waste product of various crude oil refining processes at refineries. Ammonia and hydrogen sulfide, the main contaminants of sour water, must be removed from the sour water before it can be discharged or used elsewhere in the refinery. Through a process known as stripping, the contaminants are transferred from the sour water to the gaseous stripping agent in a large stripping column containing trays or packing. The designs outlined in this report analyze the economic and environmental validity of using two alternative stripping agents, air and natural gas, compared to the industry incumbent, steam. The Net Present Value for a natural gas-fed stripper is -\$15 MM over 19 years compared to -\$16 MM for that of an air-fed stripper. One novel feature included in both designs is the option of recycling the extract stream to reduce NO<sub>x</sub> emissions in natural gas-fed burners.

Careful analysis of the economic, environmental, and safety considerations of each of the two stripping agents reveals that the natural gas stripping process is economically and efficaciously superior, while the air stripping process is environmentally superior with less safety concerns. Therefore, it is recommended that management pursues both options as potentially viable replacements for traditional sour water stripping processes.

The analysis was performed assuming an average sour water flow rate of 37.5 gallons per minute and an average ammonia concentration of 1650 ppm in the sour water feed. The recommendation of pursuing natural gas and air equivalently as stripping agents is dependent on the assumed location of the

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# Alternative Technology for Sour Water Stripping

## Disciplines

Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

## Comments

Sour water is a waste product of various crude oil refining processes at refineries. Ammonia and hydrogen sulfide, the main contaminants of sour water, must be removed from the sour water before it can be discharged or used elsewhere in the refinery. Through a process known as stripping, the contaminants are transferred from the sour water to the gaseous stripping agent in a large stripping column containing trays or packing. The designs outlined in this report analyze the economic and environmental validity of using two alternative stripping agents, air and natural gas, compared to the industry incumbent, steam. The Net Present Value for a natural gas-fed stripper is -\$15 MM over 19 years compared to -\$16 MM for that of an air-fed stripper. One novel feature included in both designs is the option of recycling the extract stream to reduce NO<sub>x</sub> emissions in natural gas-fed burners. Careful analysis of the economic, environmental, and safety considerations of each of the two stripping agents reveals that the natural gas stripping process is economically and efficaciously superior, while the air stripping process is environmentally superior with less safety concerns. Therefore, it is recommended that management pursues both options as potentially viable replacements for traditional sour water stripping processes.

The analysis was performed assuming an average sour water flow rate of 37.5 gallons per minute and an average ammonia concentration of 1650 ppm in the sour water feed. The recommendation of pursuing natural gas and air equivalently as stripping agents is dependent on the assumed location of the refinery. Because environmental regulations for water and atmospheric discharge vary by region, a separate analysis of the validity of each alternative should be performed for stripping operations in different areas.

**University of Pennsylvania**  
**Department of Chemical and Biomolecular Engineering**  
**220 South 33<sup>rd</sup> Street**  
**Philadelphia, PA 19014**



April 18, 2018

Dear Dr. Sue Ann Bidstrup-Allen and Professor Bruce Vrana,

Enclosed is an analysis of two alternative designs to traditional sour water stripping and a recommendation for the superior alternative design. The alternative designs explore the use of different stripping agents, air and natural gas, from the traditional method of using steam. The two alternative designs were compared based on their economic, environmental, and health and safety impact. Ultimately, given the slightly higher efficacy and economic advantages of natural gas as the stripping agent, and the slight safety and environmental advantages of air as the stripping agent, we recommend pursuing both approaches as equivalent alternative sour water stripping methods.

The proposed design will be able to strip the incoming sour water feed with flows ranging between 30 and 50 GPM, initial ammonia concentrations ranging between 300 and 3,000 ppm, hydrogen sulfide concentrations of 5 ppm, and trace amounts of propane, down to ammonia concentrations of 20 ppm and hydrogen sulfide concentrations of 0.1 ppm. The effluent raffinate will be discharged to the Delaware River and the effluent extract stream will be returned to the refinery feed to be used as fuel, or air, for different refinery processes, such as fired heaters. The novel approach of recycling the extract stream containing ammonia and water to the refinery's natural gas burning fired heaters will reduce harmful NO<sub>x</sub> emissions, reducing the environmental impact of the proposed process.

The refinery will be located in Philadelphia along the Delaware River and will operate for 24 hours, 333 days a year. We conducted a thorough economic analysis of the design to optimize the efficiency of the process while minimizing capital and operating expenditures. The proposed design using natural gas requires an initial investment of \$1.64 MM and has a NPV of -\$15 MM over 19 years, while the design for using air requires \$1.80 MM and has a NPV of -\$16 MM over 19 years.

Sincerely,

---

Andrew Frederick

---

Connor Leach

---

Christelle Nayandi

# Alternative Technology for Sour Water Stripping

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Section 4  
**Abstract**

Sour water is a waste product of various crude oil refining processes at refineries. Ammonia and hydrogen sulfide, the main contaminants of sour water, must be removed from the sour water before it can be discharged or used elsewhere in the refinery. Through a process known as stripping, the contaminants are transferred from the sour water to the gaseous stripping agent in a large stripping column containing trays or packing. The designs outlined in this report analyze the economic and environmental validity of using two alternative stripping agents, air and natural gas, compared to the industry incumbent, steam. The Net Present Value for a natural gas-fed stripper is -\$15 MM over 19 years compared to -\$16 MM for that of an air-fed stripper. One novel feature included in both designs is the option of recycling the extract stream to reduce NO<sub>x</sub> emissions in natural gas-fed burners. Careful analysis of the economic, environmental, and safety considerations of each of the two stripping agents reveals that the natural gas stripping process is economically and efficaciously superior, while the air stripping process is environmentally superior with less safety concerns. Therefore, it is recommended that management pursues both options as potentially viable replacements for traditional sour water stripping processes.

The analysis was performed assuming an average sour water flow rate of 37.5 gallons per minute and an average ammonia concentration of 1650 ppm in the sour water feed. The recommendation of pursuing natural gas and air equivalently as stripping agents is dependent on the assumed location of the refinery. Because environmental regulations for water and atmospheric discharge vary by region, a separate analysis of the validity of each alternative should be performed for stripping operations in different areas.

Section 5

# Introduction and Objective-time Chart

## Section 5.1: Introduction

Sour water is a ubiquitous wastewater product of crude oil refineries, where it flows as an effluent from atmospheric and vacuum distillation towers.<sup>1</sup> Sour water typically contains high amounts of ammonia (100-8,000 ppm) and hydrogen sulfide (300-12,000 ppm), as well as lower amounts of light hydrocarbons, which must be removed before the water can be discharged downstream or reused in the refinery.<sup>2</sup> Depending on the composition of the stripped water, it can either be reused as wash water for the hydrodesulfurization process and makeup water for the crude desalting process, or it can be discharged to a downstream purification plant or even released directly to the sewer or river.<sup>3</sup>

A stripping operation must take into account phase equilibria, in this case Henry's Law (and its temperature dependence), for each component being stripped. The relationship between liquid fraction and vapor fraction is the driving force behind this type of separation. Another important factor to consider is the chemical equilibria of the water-dissolved gases, which dissociate into ions that cannot be stripped. Using pH manipulation and Le Chatelier's Principle, it is possible and advantageous to control the relative amounts of dissolved gases and ions in order to optimize the desired separation in a given column.

The components are traditionally removed in a multi-step process, depending on the contaminants that need to be removed. This process often includes a degasification step, which removes hydrogen and light alkanes.<sup>4</sup> While degasification is only necessary if light hydrocarbons

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<sup>1</sup> "Sour Water Stripper Process." *Yokogawa America*, Yokogawa Electric Corporation, 2 Aug. 2016, [www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/](http://www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/).

<sup>2</sup> Stevens, D. K., and A. Mosher. "Fundamentals of Sour Water Stripping." *Brimstone Sulfur Symposia*, Vail, Colorado. 2008.

<sup>3</sup> Weiland, R.H., et al. "Stripping Phenolic Water." *Protreat.com*, 2013, [www.protreat.com/files/publications/85/S\\_344\\_sour\\_water\\_prf4.pdf](http://www.protreat.com/files/publications/85/S_344_sour_water_prf4.pdf).

<sup>4</sup> "Sour Water Stripper Process." *Yokogawa America*, Yokogawa Electric Corporation, 2 Aug. 2016, [www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/](http://www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/).

are present, the process always includes a series of steam-strippers, using either live steam or a reboiler, to remove the basic ammonia and the acidic hydrogen sulfide and/or carbon dioxide.<sup>5</sup> This is generally accomplished with a two-column setup, with one low-pH (5-6) column to remove the acidic compounds followed by a high-pH column (10-12) to remove the basic ammonia.<sup>6</sup> Occasionally a one-column approach with a pH around 8 may be used if the stripping goals are to a lesser extent than normal.<sup>7</sup>

Our design prompt details our incoming sour water feed as having 300-3,000 ppm ammonia, 5 ppm hydrogen sulfide, and trace amount of propane. Because of the relative contaminant concentrations, we interpret this stream as having already been subjected to degasification, which left 1 ppm propane in the sour water stream, and hydrogen sulfide stripping, which removed all but 5 ppm of the initial hydrogen sulfide concentration.

The focus of this publication is to examine the use of alternative stripping agents, natural gas and air, to remove the remaining ammonia and hydrogen sulfide in the sour water feed. These alternative stripping agents have potential benefits compared to the industry incumbent, steam, worth exploring. However, the effectiveness of natural gas and air as stripping agents and their impact on the environment remain to be fully understood. This paper will serve to evaluate the two alternative stripping agents with respect to economics, safety, and environmental impact.

For this investigation, the following assumptions were made regarding the process. The sour water stripping operation is performed by the wastewater treatment division of a petroleum

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<sup>5</sup> Addington, Luke, et al. "Sour water: Where it comes from and how to handle it." *Bryan Research and Engineering Inc.* [online]. Disponible en: <https://www.bre.com/PDF/Sour-Water-Where-It-Comes-from-and-How-to-Handle-It.pdf> (2011).

<sup>6</sup> Stevens, D. K., and A. Mosher. "Fundamentals of Sour Water Stripping." *Brimstone Sulfur Symposia*, Vail, Colorado. 2008.

<sup>7</sup> "Sour Water Stripper Process." *Yokogawa America*, Yokogawa Electric Corporation, 2 Aug. 2016, [www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/](http://www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/).

refinery just north of Philadelphia, PA, along the Delaware River. The stripping process takes place on-site at the refinery, and has access to refinery utilities like steam, electricity, and natural gas. Natural gas is assumed to be 100% methane. The refinery is of average size for the east coast region. The refinery is assumed to operate for 8000 hours per year, the standard number given for a continuous industrial process in the second edition of *Chemical Engineering Design* by Towler and Sinnott, 2013.<sup>8</sup>

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<sup>8</sup> Towler, Gavin, and Ray K. Sinnott. *Chemical engineering design: principles, practice and economics of plant and process design*. Elsevier, 2012.



## Section 5.2: Objective-time Chart

### Specific Goals:

- Develop a stripping operation that can treat 75,000 tons of sour water per year, with a standard flow rate between 30 and 50 GPM, and an  $\text{NH}_3$  concentration ranging from 300-3000 ppm. The process must reduce the  $\text{NH}_3$  to under 20 ppm and the  $\text{H}_2\text{S}$  to under 0.1 ppm.
- Compare air to natural gas as a stripping agent, and using economics, and environmental and safety concerns, determine the superior stripping agent.

### Project Scope:

- In Scope
  - Reduce the ammonia in the sour water stream from 300-3000 ppm to 20 ppm
  - Reduce the hydrogen sulfide in the sour water stream from 5 ppm to 0.1 ppm
  - Compare air and natural gas as stripping agents from an environmental, safety, and economic perspective
  - Determine the effect of adjusting the pH on the stripping process
  - Determine the equipment needed and its appropriate design and size
  - Determine the bare module capital cost of each process unit and its associated operating cost
  - Conduct a thorough environmental analysis of liquid phase and gas phase effluents
- Out of Scope
  - An accurate ASPEN Plus V10 simulation combining pH adjustments and Murphree tray efficiencies
  - Refinery plant capacity and specifics
  - Existing permits for the refinery
  - Henry's Law constants

### Deliverables:

- Present block results and operating conditions for each unit
- Develop a detailed equipment design for the stripping units
- Create a process flow sheet with mass and energy balances
- Provide financial and environmental analyses.

### Process Development Timeline:

- Complete mid-semester presentation by February 27, 2018
- Complete 6 deliverables over the course of the semester, with the final report completed by April 17th, 2018.

Section 6  
**Innovation Map**

*N/A*

Section 7  
**Market and Competitive Analyses**

*N/A*

Section 8

# Customer Requirements

For our process, there is no traditional customer. We are not selling a product to a customer for revenue. However, we are offering a service that can severely impact both the immediate and distant communities. For that reason, the health and safety of the various communities and surrounding ecosystems must be considered. To ensure the safety of the communities, federal agencies such as the Environmental Protection Agency (EPA) and state agencies such as the Department of Environmental Protection (DEP) impose effluent concentration requirements on the raffinate and extract streams. For the sweet water raffinate, the ammonia (and ammonium) must be stripped down to a sum of 20 ppm. Additionally, the hydrogen sulfide and its dissociated species must be stripped beyond detectable limits, which is equivalent to less than 0.10 ppm. Because these species are less harmful in air than in water,<sup>9</sup> the emission limits for releasing ammonia and hydrogen sulfide into the air are more lax than those of water. It is for this reason that the sour water stripper is an effective technology. For an in-depth discussion of the environmental considerations, see Section 23.1.

In addition to the surrounding communities, the refinery also acts as a customer. The sour water stripper must be designed with the capacity to strip 75,000 tons of sour water, a byproduct of the refinery, per year with flows ranging between 20-50 GPM. The standard flow of the sour water will be 30-50 GPM, and will drop to 20 GPM around annual plant shutdown. The refinery will also be a customer from the economic standpoint. Because the sour water stripper generates no revenue, it is not a profitable unit. Therefore, the only economic goal in the construction and operation of the unit will be to minimize its cost.

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<sup>9</sup> Lee, D., et al. "Dynamic simulation of the sour water stripping process and modified structure for effective pressure control." *Chemical Engineering Research and Design* 80.2 (2002): 167-177.

Section 9  
**Critical-to-quality (CTQ) Variables**

*N/A*

Section 10  
**Product Concepts**

*N/A*

Section 11  
**Superior Product Concepts**

*N/A*



Section 12  
**Competitive (patent) Analysis**

*N/A*

Section 13

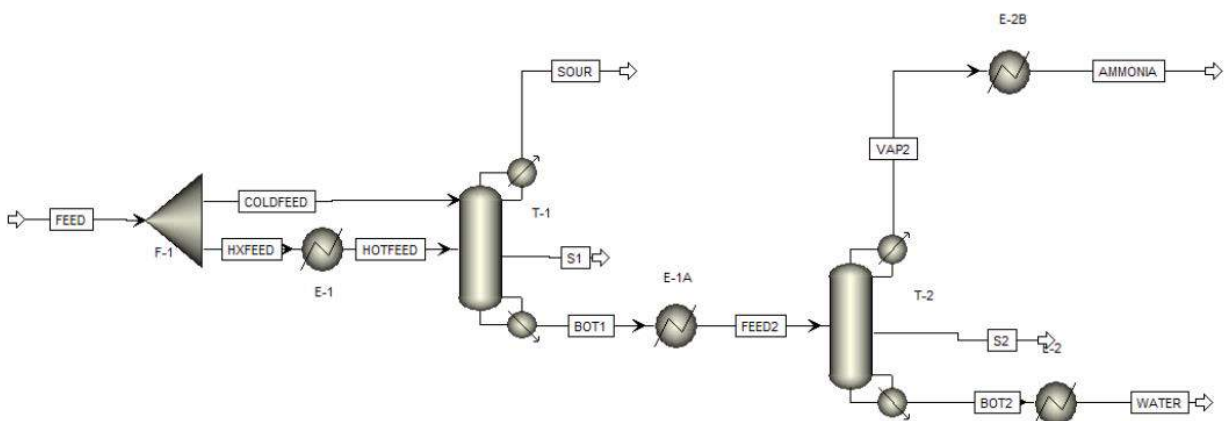
# Preliminary Process Synthesis

Across the refinery industry, stripping systems for sour water can vary depending on the relative amounts of different contaminants, differing standards for sweet water purity, and available stripping media. Most industrial sour water strippers use steam as the stripping medium, either from the refinery’s utilities, or by boiling a portion of the sour water itself.

### Section 13.1: ASPEN Traditional Sour Water Stripping Approach

While our process does not use steam as the stripping agent, we initiated our design optimization process by simulating a steam stripping operation in ASPEN Plus V10, namely ASPEN’s sour water stripping tutorial, which models a two-column stripping approach (Figure 13.1). The first column was operated at a lower, more acidic pH, and removed the hydrogen sulfide from the sour water. The second column was operated at a higher more basic pH, removing the ammonia. Although this system is not in line with our project specifications, it successfully removed our contaminants and was a good way to familiarize ourselves with using ASPEN for stripping.

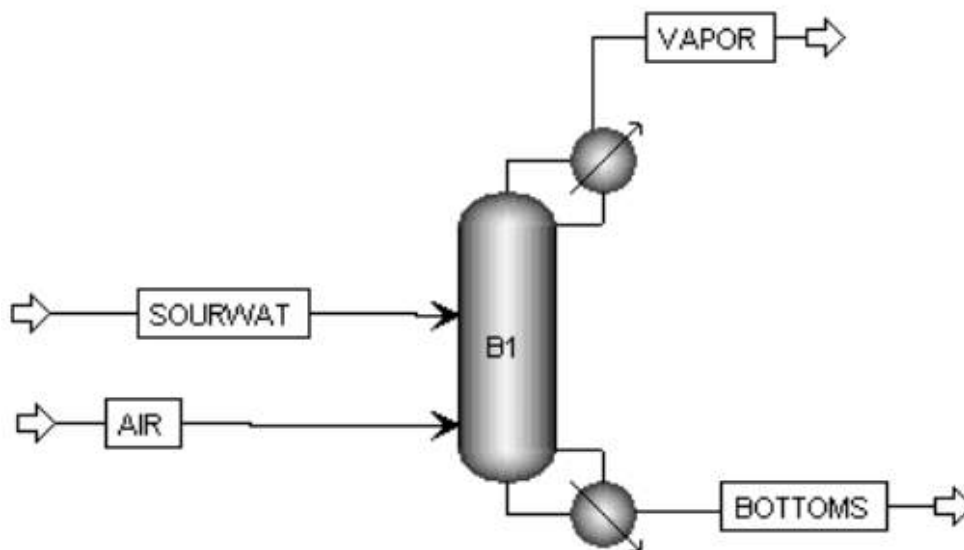
**Figure 13.1:** ASPEN Sour Water Tutorial Using Steam as Stripping Agent



### Section 13.2: Preliminary Sour Water Stripper with Air

Implementing the useful features of the steam stripping tutorial, namely the electrolyte package, RADFRAC column setup, and design specification format, we designed a similar process using air as the incoming stripping agent. The column had a condenser and reboiler, which circulated steam and water within the system (Figure 13.2). This approach achieved the necessary requirements for ammonia and hydrogen sulfide, but this system had an inherent flaw. The reboiler and condenser circulate water and steam within the column, and the steam made by the reboiler flows upward through the column, stripping the sour water as it does. The condenser then removed the water vapor from the extract, leaving only air and the contaminants to leave the system. While this approach appeared to be successful as an air-stripping operation from a material balance perspective, the goal of the project is to use air itself as the stripping agent, not just as a carrier for the contaminants stripped by steam. We left this model behind and moved forward with column designs that did not have a reboiler or condenser.

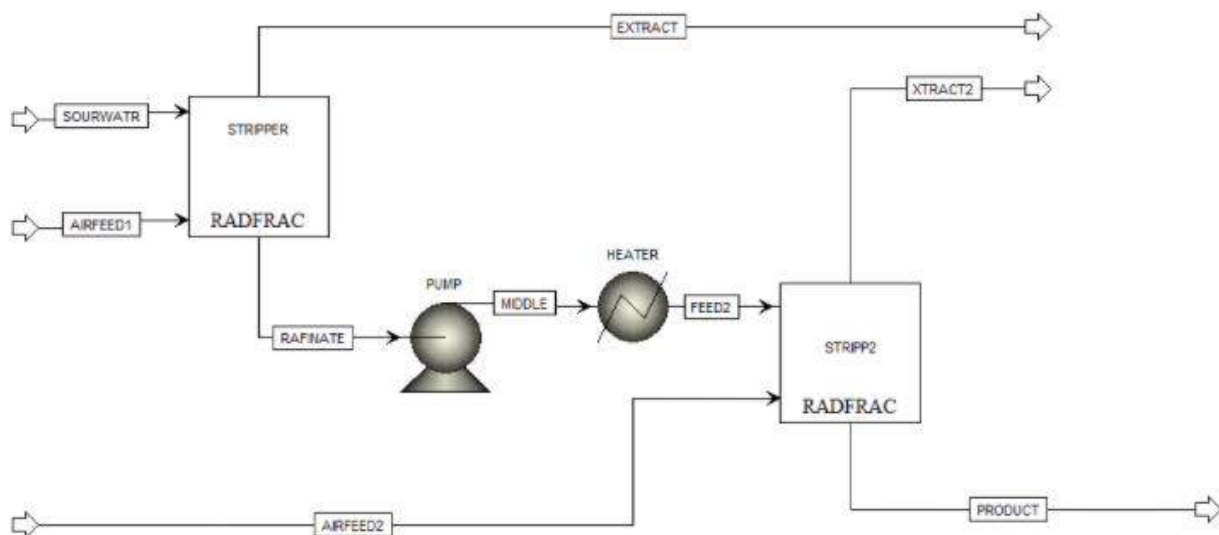
**Figure 13.2:** Preliminary Sour Water Stripper with Condenser and Reboiler



### Section 13.3: Preliminary Design with Two Sour Water Strippers

Our next stripping process simulation incorporated 2 columns, both without condensers or reboilers (Figure 13.3). We were still simulating with preliminary conditions: reboiler and condenser, absorber set to off, low incoming air temperature, dissociation reactions not activated, and using ideal stages. Because of the simulation conditions, ASPEN would return errors if we had too high or low of a stripping media flow rate. Some of these errors we interpreted as legitimately process-related, such as stages drying up if our air flow rate was too high; but others did not make intuitive sense or appeared to be simulation-related. Because of these restraints, we were not able to strip the sour water to the required levels of contaminants with only one column, so we directed the raffinate of the first column into a second column which allowed us to sufficiently remove the contaminants. While this fulfilled our project specifications, we needed to incorporate all the necessary simulation features, such as tray efficiency and electrolytics, for fullest accuracy. Once these were enabled, we were able to remove all contaminants with a single column, so we abandoned the two-column approach for good.

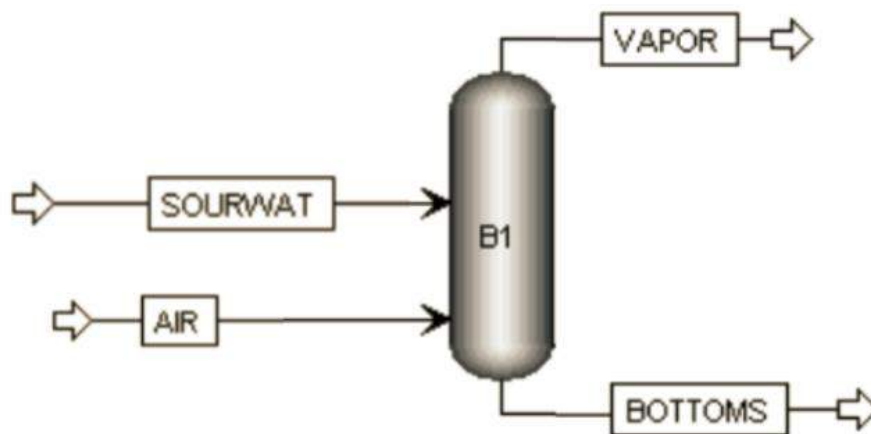
**Figure 13.3:** Preliminary Design with Two Sour Water Stripping Columns



### Section 13.4: One Column Stripper Design

The decision to move forward with the one-column approach finalized, we activated the final input and column parameters, making the simulation as accurate to reality as possible. Inside the column, with differential contaminant concentrations, pH, and temperature all varying among the trays, the type of tray and correct tray efficiency were implemented. Figure 13.4 shows the simplistic one-column design, essentially a block flow diagram (BFD) for our system since the stripper is the only process unit where an important reaction or separation takes place. While this simple diagram serves as a BFD, it is not comprehensive of the other process equipment needed, such as heaters, pumps, storage tanks, or control systems.

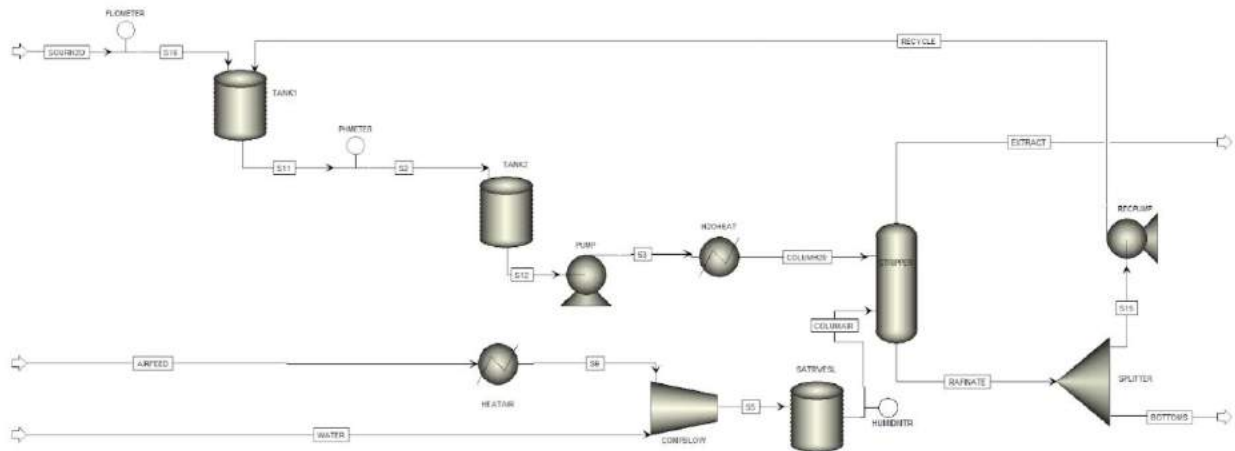
**Figure 13.4:** One Column Stripper Design: Block Flow Diagram



### Section 13.5: Process Design with Preliminary Equipment Integration

The next step in our process design was incorporating the other equipment necessary to run a sour water stripping operation. Figure 13.5 shows the stripping process with early-stage associated equipment.

**Figure 13.5:** Process Design with Preliminary Equipment Integration



The flow diagram includes heaters and pressure changers for both the sour water and gas streams. For the sour water stream, there is a surge/recycle tank and one tank which was envisioned as a delay mechanism so the control system would have time to adjust the stripping agent flow rate to meet the needs of the sour water. The major breakthrough that was introduced during this iteration of our process is the addition of water vapor to the stripping agent stream. While optimizing the stripping column, we found that the temperature inside the column (affected by the temperatures of the incoming sour water and stripping agent streams) had a positive effect on the extent of the stripping. We realized that a substantial amount of sour water was vaporizing and cooling the column, so we added water vapor to our stripping agent gas to reduce the amount of water that could vaporize in the column. This had the effect of increasing the operating temperature of the stripping column, and yielded, for the first time, a fully successful ASPEN

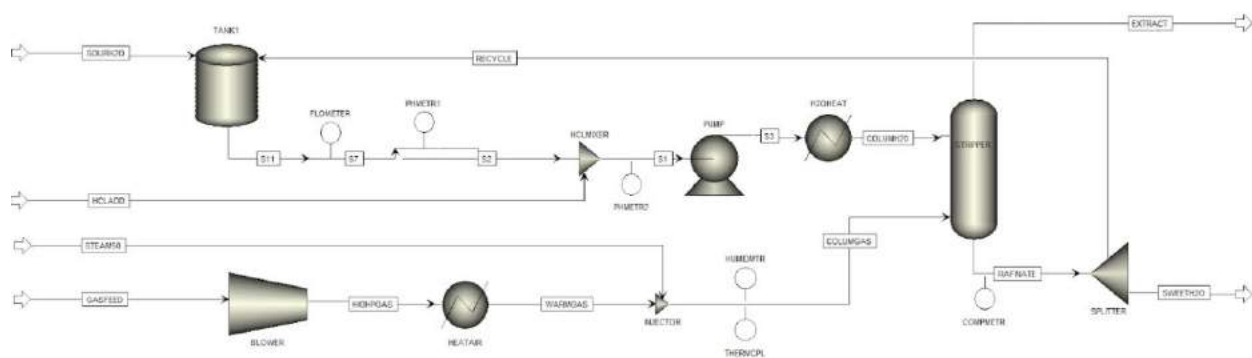
simulation with every process variable engaged (i.e. electrolytics, absorber, tray efficiency, etc.). For the gas stream, there is a blower and then saturation vessel for adding humidity to the gas stream. This diagram also includes several measurement devices, including a flow meter, pH meter, and humidity meter. There is a pump in line with the recycle stream to propel the diverted raffinate stream to the surge tank.



### Section 13.6: Nearly Finalized Process Design

The next iteration of our process design corrected for the inadequacies of the previous flowsheet. The design of an efficient process design (Figure 15.3) and the pressure of the raffinate (Tables 15.1 and 15.3) eliminate the need for a recycle pump. We found that steam injection is a far more cost-effective method to add humidity to a stream compared to vaporizing large amounts of water. The flow diagram in Figure 13.6 now features both the pH and flow meters downstream of the surge tank, to better monitor the composition and flow rate of the sour water entering the stripping column. There is now a mixer to add a small amount of acid to our sour water, which we optimized to create column interior conditions to best strip both ammonia and hydrogen sulfide. There is a pH meter after the acid adder to keep track of the pH of the sour water entering the column. The gas feed stream is now accurately represented by a blower to pressurize the air, then a heater, then steam injectors to add humidity to the stream. A thermocouple and humidity meter are downstream of the steam injection point to control the heat duty of the heater, and amount of steam which is injected.

**Figure 13.6:** Nearly Finalized Process Design with Equipment



The final iteration of our process design are the finalized flowsheets (Figures 15.1 and 15.2) that can be found in Section 15: Process Flow Diagram and Material Balances.

Section 14  
**Assembly of Database**

### Section 14.1: Process Simulation Setup

The simulations modeling the sour water process were designed using ASPEN Plus V10. To accurately depict the dissociation of ammonia and hydrogen sulfide in water, the electrolyte package in ASPEN was turned on. Said package enables the partial dissociation equilibria of molecular species. In this instance the major dissociation reactions are listed in Table 14.1. The sour water stripping tutorial on ASPEN was followed to set up our simulation. However, the tutorial was quickly abandoned because it used steam as the stripping agent, which required equipment like a reboiler and condenser that deviated from our process.

**Table 14.1:** Equilibrium Dissociation Reactions

Electrolyte Reaction	Chemical Equation
Water Dissociation	$2 \text{H}_2\text{O} \leftrightarrow \text{H}_3\text{O}^+ + \text{OH}^-$
Ammonia Dissociation	$\text{NH}_3 + \text{H}_2\text{O} \leftrightarrow \text{NH}_4^+ + \text{OH}^-$
Hydrogen Sulfide Dissociation	$\text{H}_2\text{O} + \text{H}_2\text{S} \leftrightarrow \text{H}_3\text{O}^+ + \text{HS}^-$
Bisulfide Dissociation	$\text{H}_2\text{O} + \text{HS}^- \leftrightarrow \text{H}_3\text{O}^+ + \text{S}^{2-}$
Sulfuric Acid Dissociation	$\text{H}_2\text{O} + \text{H}_2\text{SO}_4 \leftrightarrow \text{H}_3\text{O}^+ + \text{HSO}_4^-$
Hydrogen Sulfate Dissociation	$\text{H}_2\text{O} + \text{HSO}_4^- \leftrightarrow \text{H}_3\text{O}^+ + \text{SO}_4^{2-}$

Turning on the electrolytic package is especially important in this simulation because the pH plays an important role in determining how much of a species can be stripped. For example, a dissociated ion cannot be stripped from water because its charge interacts with the polar water molecules. Altering the pH of the solution will determine how much of a given molecule is dissociated. In basic conditions for example, equilibria will favor the formation of ammonia over ammonium and the dissociated sulfide ions over hydrogen sulfide.

The Electrolyte Wizard on ASPEN automatically generates all possible ionic species and reactions for the H<sub>2</sub>O-NH<sub>3</sub>-H<sub>2</sub>S system. For the purpose of this simulation, all precipitates are considered to be negligible. The apparent component approach for the Electrolyte Wizard was selected. This approach describes solution chemistry as part of the physical property calculations and reports the component flow rates of the apparent components as if no dissociation occurred. Once the pH of the solution was further analyzed, the apparent species approach was changed to the true species approach to distinguish between dissociated and undissociated species.

The Electrolyte Wizard also automatically updates the Henry's constants as a function of temperature and the dissociation reaction equilibrium constants as a function of temperature. These values are dependent on the thermodynamic simulation method assigned in ASPEN. The ENTRL-RK method was chosen because it is optimized for electrolyte reactions, Henry's Law, and ionic components. The method also influences the interactions of the species which is accounted for through the "Binary Interactions" section. All in all, the electrolytic package accurately accounts for the dissociation and interaction of the species, which is vital for the proper modeling of a sour water stripper.

Additional ASPEN simulation modifications include setting the convergence method to the Broyden Method, a variant of Newton's Method that converges more quickly in fewer loops. The absorber option for the column was set to on. The absorber option is necessary for a RADFRAC column if there is no condenser or reboiler, because it controls the inside-loop convergence for the standard algorithm.

**Section 14.2: Table of Acronyms**

**Table 14.2:** Comprehensive Table of Acronyms

Acronym	Meaning
MM	Million
MOC	Material of Construction
BFW	Boiler Feed Water
ID & OD	Interior Diameter & Outside Diameter
SCF	Standard Cubic Feet
SCF(M,H,D,Y)	Standard Cubic Feet per (Minute, Hour, Day, Year)
CF(M,H,D,Y)	Cubic Feet per (Minute, Hour, Day, Year)
ppm	Parts per Million
GPM	Gallons per Minute
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
DEP	Department of Environmental Protection
EPA	Environmental Protection Agency
NPV	Net Present Value
LEL	Lower Explosion Limit
NAAQS	National Ambient Air Quality Standards
DRBC	Delaware River Basin Commission
CWA	Clean Water Act
CFR	Code of Federal Regulations

Section 15

# Process Flow Diagram and Material Balances

Figure 15.1: Process Flow Diagram for Air Stripping Process

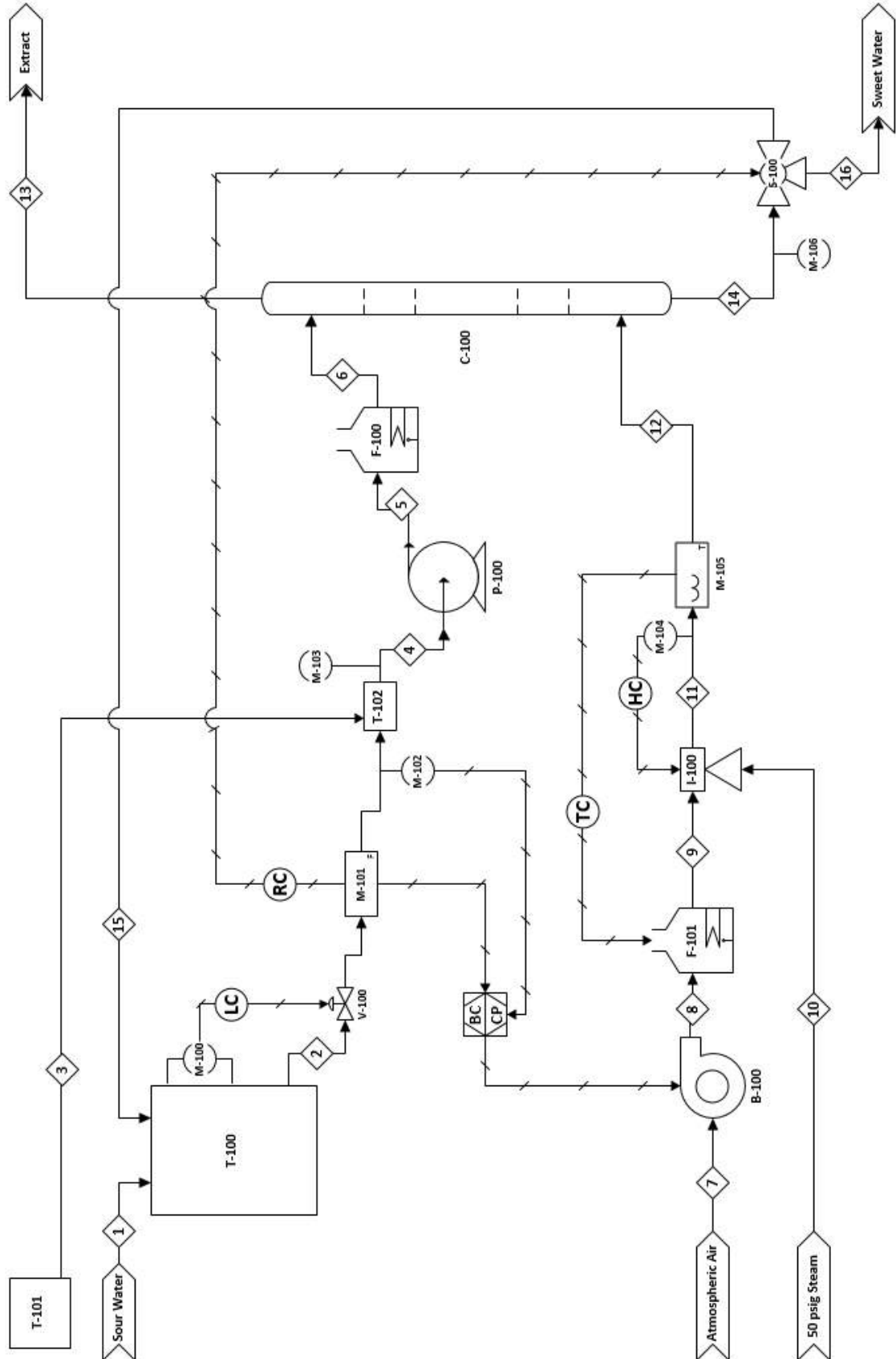


Table 15.1: Stream Table for Air Stripping Process

Stream Number (Air)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Temperature (°F)	80	80	80	80	80	190	70	70	158	300	190	190	153	137	137	137
Pressure (psia)	15	15	15	15	55	55 to 25	14.7	35	35	50	35	35	17	18.8	18.8	18.8
Pressure (psig)	0.3	0.3	0.3	0.3	40.3	40.3 to 10.3	0	20.3	20.3	35.3	20.3	20.3	2.3	4.1	4.1	4.1
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0
Molar flow (lbmol/hr)	1006	1006	0.073	1006.1	1006.1	1006.1	N/A	831.6	831.6	92.4	92.4	92.4	989.5	940.5	0.0	940.5
Volume flow (GPM)   (cfh)	37.5	37.5	0.023	37.5	37.5	37.5	N/A	134894	157436	14803	183841	183841	382357	34.4	0.0	34.4
Mass flow (lb/hr)	18122.4	18122.4	1.8	18124.2	18124.2	18124.2	N/A	23992	23992	1665	25657	25657	26837	16944.2	0.0	16944.2
Component mass flow (lb/hr)																
H <sub>2</sub> O	18092	18092	1.09	18093.3	18093.3	18093.3	0.0	0.0	0.0	1665	1665	1665	2813	16943	0.0	16943
NH <sub>3</sub>	29.48	29.48	0.0	29.36	29.36	29.36	0.0	0.0	0.0	0.0	0.0	0.0	29.8	0.102	0.0	0.102
NH <sub>4</sub> <sup>+</sup>	0.442	0.442	0.0	0.577	0.577	0.577	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.227	0.0	0.227
H <sub>2</sub> S	8.08E-05	8.08E-05	0.0	1.03E-04	1.03E-04	1.03E-04	0.0	0.0	0.0	0.0	0.0	0.0	9.05E-02	3.60E-06	0.0	3.60E-06
HS <sup>-</sup>	0.0878	0.0878	0.0	0.0878	0.0878	0.0878	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000104	0.0	0.000104
S <sup>-</sup>	4.86E-05	4.86E-05	0.0	3.90E-05	3.90E-05	3.90E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.00E-10	0.0	2.00E-10
C <sub>3</sub> H <sub>8</sub>	0.018	0.018	0.0	0.018	0.018	0.018	0.0	0.0	0.0	0.0	0.0	0.0	0.018	0.0	0.0	0.0
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.94	29.94	0.0	29.94	29.94	29.94	0.0	0.0	0.0	0.0	0.0	0.0	29.80	0.33	0.0	0.33
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>-</sup> )	0.0879	0.0879	0.0	0.0879	0.0879	0.0879	0.0	0.0	0.0	0.0	0.0	0.0	0.0905	0.0001	0.0	0.0001
H <sub>2</sub> O <sup>+</sup>	1.06E-07	1.06E-07	1.20E-01	1.40E-07	1.40E-07	1.40E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.46E-06	0.0	2.46E-06
OH <sup>-</sup>	0.372	0.372	0.0	0.291	0.291	0.291	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00276	0.0	0.00276
N <sub>2</sub>	0.0	0.0	0.0	0.0	0.0	0.0	18404.1	18404.1	18404.1	0.0	18404.1	18404.1	18403.9	0.2	0.0	0.2
O <sub>2</sub>	0.0	0.0	0.0	0.0	0.0	0.0	5588.2	5588.2	5588.2	0.0	5588.2	5588.2	5588.1	0.1	0.0	0.1
CH <sub>4</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H <sub>2</sub> SO <sub>4</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H <sub>2</sub> O <sup>+</sup>	0.0	0.0	5.88E-01	1.50E-07	1.50E-07	1.50E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.02E-06	0.0	1.02E-06
SO <sub>4</sub> <sup>++</sup>	0.0	0.0	0.0054	0.588	0.588	0.588	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.596	0.0	0.596
Component mass fraction																
H <sub>2</sub> O	0.9983	0.9983	0.605	0.9983	0.9983	0.9983	0.0 (to 0.04)	0.0	0.0	1.0	0.0649	0.0649	0.1049	0.9996	0.9996	0.9996
(O <sub>2</sub> ) + (N <sub>2</sub> )	0.0	0.0	0.0	0.0	0.0	0.0	1.0 (to 0.96)	1.0	1.0	0.0	0.935	0.935	0.894	0.0	0.0	0.0
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	0.00165	0.00165	0.0	0.00165	0.00165	0.00165	0.0	0.0	0.0	0.0	0.0	0.0	0.00111	0.0000194	0.0000194	0.0000194
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>-</sup> )	4.85E-06	4.85E-06	0.0	4.85E-06	4.85E-06	4.85E-06	0.0	0.0	0.0	0.0	0.0	0.0	3.37E-06	6.40E-09	6.40E-09	6.40E-09
C <sub>3</sub> H <sub>8</sub>	1.00E-06	1.00E-06	0.0	1.00E-06	1.00E-06	1.00E-06	0.0	0.0	0.0	0.0	0.0	0.0	6.75E-07	0.0	0.0	0.0



**Table 15.2:** Equipment (block) Table for Air Stripping Process

<b>Block Number (Air)</b>	<b>Block Type</b>	<b>Block Description</b>
T-100	Tank	Surge Tank
T-101	Tank	Acid Storage Tank
T-102	Tank	Mixing Tank
P-100	Pump	Sour Water Pump
F-100	Fired Heater	Sour Water Heater
F-101	Fired Heater	Air Heater
V-100	Valve	Level Control Valve
B-100	Blower	Air Blower
I-100	Injector	Steam Injector
C-100	Column	Stripping Column
S-100	Splitter	Recycle Splitter
M-100	Measurement	Surge Tank Level Meter
M-101	Measurement	Sour Water Flow Meter
M-102	Measurement	pH Meter 1
M-103	Measurement	pH Meter 2
M-104	Measurement	Humidity Meter
M-105	Measurement	Thermocouple
M-106	Measurement	Concentration Meter
LC	Level Controller	Level P-Control System
RC	Recycle Controller	Low-Flow Recycle Controller
BC   CP	Blower Control Computer	Air Feed Control Computer
TC	Temperature Controller	Heater Control System
HC	Humidity Controller	Steam Control System

Figure 15.2: Process Flow Diagram for Natural Gas Stripping Process

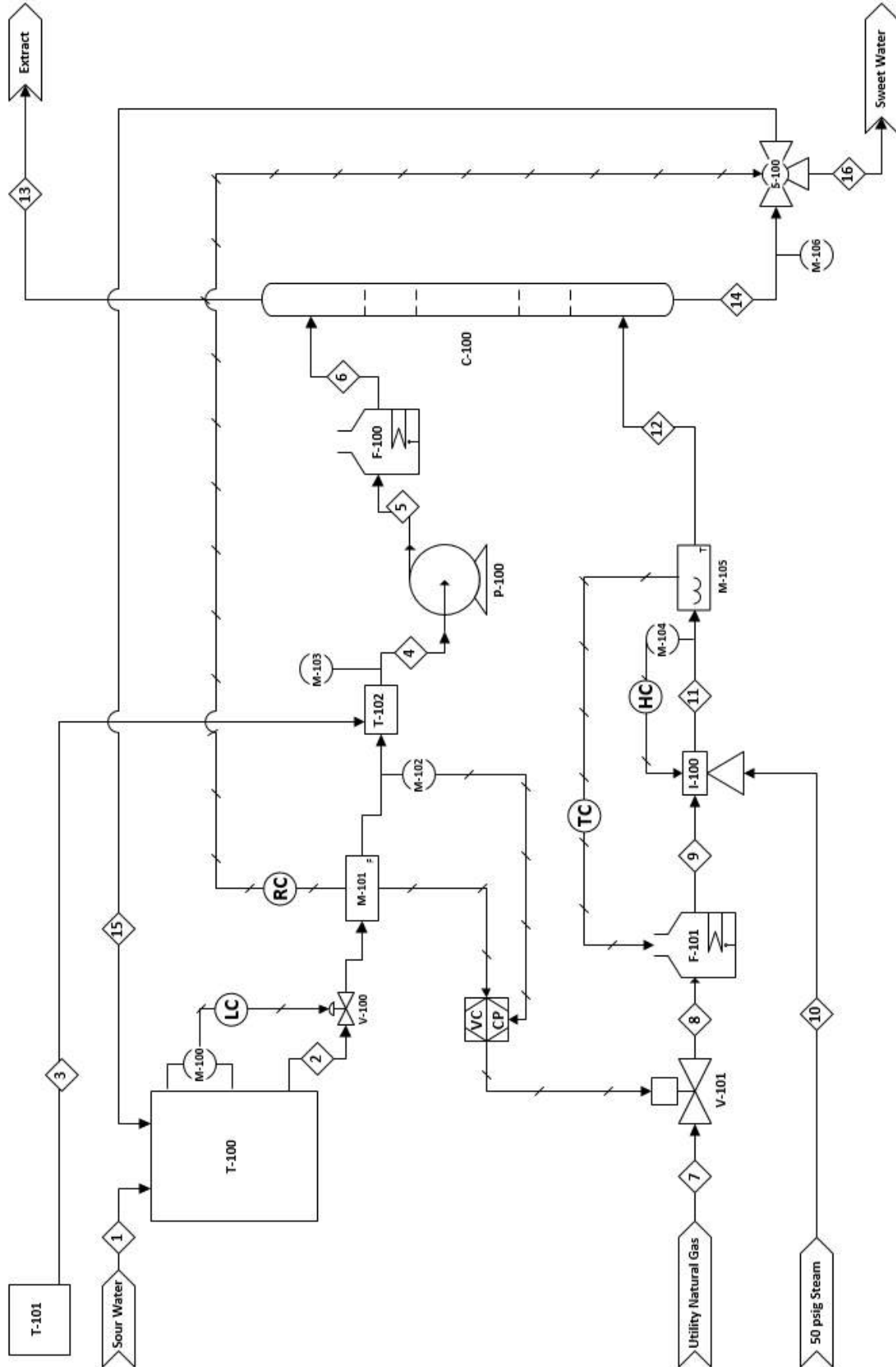
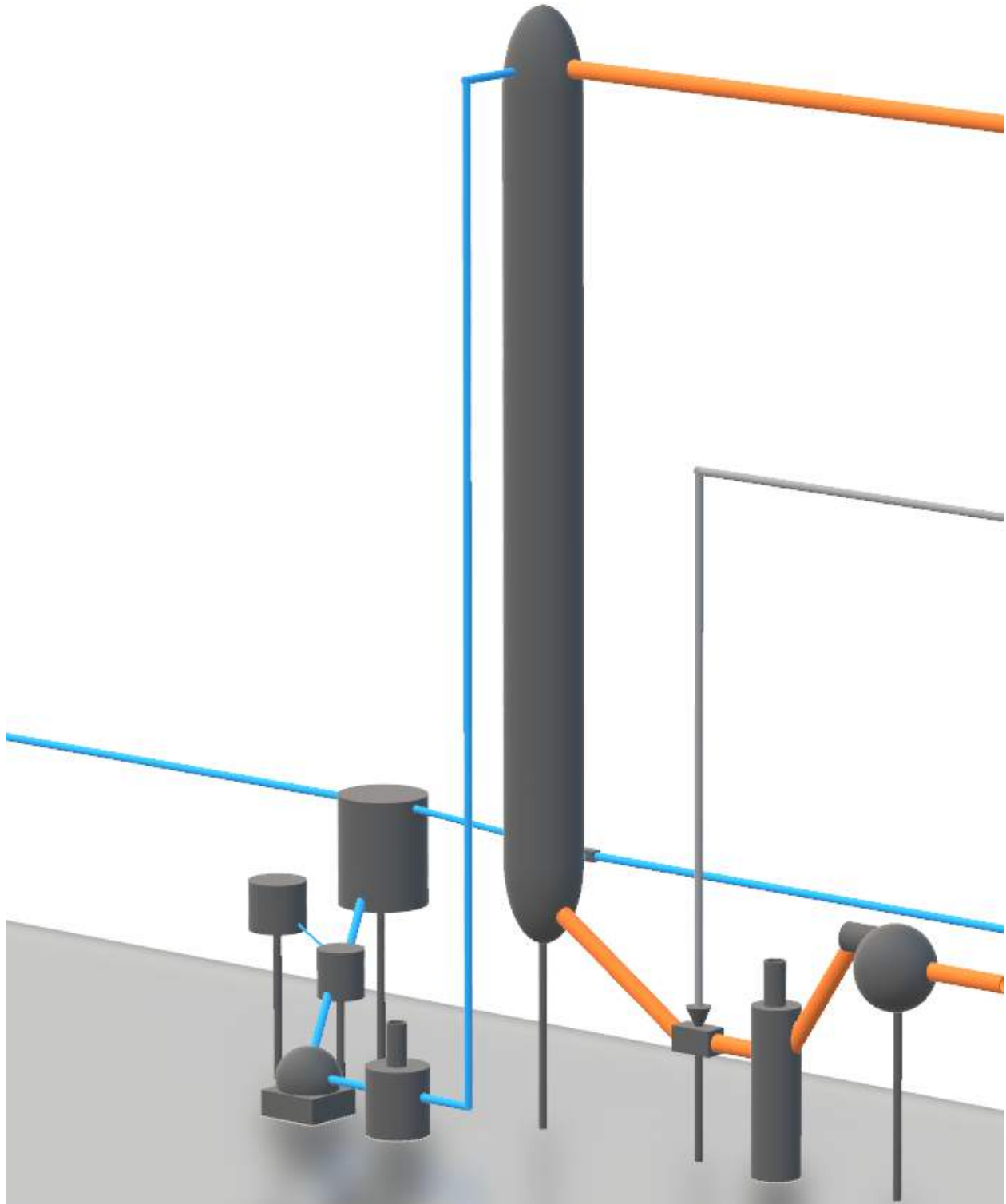


Table 15.3: Stream Table for Natural Gas Stripping Process

Stream Number (Natural Gas)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Temperature (°F)	80	15	15	15	80	190	70	42	180	300	190	190	151.5	140	140	140
Pressure (psia)	15	15	0.3	0.3	55	55 to 25	514.7	35	35	50	35	35	17	18.6	18.6	18.6
Pressure (psig)	0.3	0.3	0.3	0.3	40.3	40.3 to 10.3	500	20.3	20.3	35.3	20.3	20.3	2.3	3.9	3.9	3.9
Vapor Fraction	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0
Molar flow (lbmol/hr)	1006	1006	0.067	1006.1	1006.1	1006.1	912.8	912.8	912.8	101.4	101.4	101.4	1083.1	937.2	0.0	937.2
Volume flow (GPM   cth)	37.5	37.5	0.021	37.5	37.5	37.5	9422.5	139626	178623	16243	201370	201370	416849	34.3	0.0	34.3
Mass flow (lb/hr)	18122.4	18122.4	1.65	18124	18124	18124	14644	14644	14644	1827	16471	16471	17711.9	16883.1	0.0	16883.1
Component mass flow (lb/hr)																
H <sub>2</sub> O	18092	18092	1	18093	18093	18093	0.0	0.0	0.0	1827	1827	1827	3037	16882.8	0.0	16882.8
NH <sub>3</sub>	29.48	29.48	0.0	29.37	29.37	29.37	0.0	0.0	0.0	0.0	0.0	0.0	29.6	0.118	0.0	0.118
NH <sub>4</sub> <sup>+</sup>	0.442	0.442	0.0	0.5645	0.5645	0.5645	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.209	0.0	0.209
H <sub>2</sub> S	8.08E-05	8.08E-05	0.0	1.01E-04	1.01E-04	1.01E-04	0.0	0.0	0.0	0.0	0.0	0.0	8.77E-02	6.23E-06	0.0	6.23E-06
HS <sup>-</sup>	0.0878	0.0878	0.0	0.0878	0.0878	0.0878	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.000226	0.0	0.000226
S <sup>-2</sup>	4.86E-05	4.86E-05	0.0	3.95E-05	3.95E-05	3.95E-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.59E-10	0.0	5.59E-10
C <sub>3</sub> H <sub>8</sub>	0.018	0.018	0.0	0.018	0.018	0.018	0.0	0.0	0.0	0.0	0.0	0.0	0.018	0.0	0.0	0.0
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.92	29.92	0.0	29.93	29.93	29.93	0.0	0.0	0.0	0.0	0.0	0.0	29.60	0.33	0.0	0.33
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>-2</sup> )	0.0879	0.0879	0.0	0.0879	0.0879	0.0879	0.0	0.0	0.0	0.0	0.0	0.0	0.0877	0.0002	0.0	0.0002
H <sub>2</sub> O <sup>+</sup>	1.06E-07	1.06E-07	1.10E-01	1.35E-07	1.35E-07	1.35E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.03E-06	0.0	2.03E-06
OH <sup>-</sup>	0.372	0.372	0.0	0.296	0.296	0.296	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00346	0.0	0.00346
N <sub>2</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O <sub>2</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CH <sub>4</sub>	0.0	0.0	0.0	0.0	0.0	0.0	14644.0	14644.0	14644.0	0.0	14644.0	14644.0	14643.7	0.3	0.0	0.3
H <sub>2</sub> SO <sub>4</sub>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H <sub>2</sub> SO <sub>4</sub> <sup>+</sup>	0.0	0.0	5.40E-01	1.34E-07	1.34E-07	1.34E-07	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.95E-07	0.0	7.95E-07
SO <sub>4</sub> <sup>-2</sup>	0.0	0.0	0.005	0.539	0.539	0.539	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.546	0.0	0.546
Component mass fraction																
H <sub>2</sub> O	0.9983	0.9983	0.604	0.9983	0.9983	0.9983	0.0	0.0	0.0	1.0	0.111	0.111	0.171	1.0	1.0	1.0
CH <sub>4</sub>	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.889	0.889	0.827	0.000016	0.0	0.000016
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	0.00165	0.00165	0.0	0.00165	0.00165	0.00165	0.0	0.0	0.0	0.0	0.0	0.0	0.00167	0.0000194	0.0000194	0.0000194
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>-2</sup> )	4.85E-06	4.85E-06	0.0	4.85E-06	4.85E-06	4.85E-06	0.0	0.0	0.0	0.0	0.0	0.0	4.95E-06	1.35E-08	1.35E-08	1.35E-08
C <sub>3</sub> H <sub>8</sub>	1.00E-06	1.00E-06	0.0	1.00E-06	1.00E-06	1.00E-06	0.0	0.0	0.0	0.0	0.0	0.0	1.02E-06	0.0	0.0	0.0

**Table 15.4:** Equipment (block) Table for Natural Gas Stripping

<b>Block Number (Natural Gas)</b>	<b>Block Type</b>	<b>Block Description</b>
T-100	Tank	Surge Tank
T-101	Tank	Acid Storage Tank
T-102	Tank	Mixing Tank
P-100	Pump	Sour Water Pump
F-100	Fired Heater	Sour Water Heater
F-101	Fired Heater	Natural Gas Heater
V-100	Valve	Level Control Valve
V-101	Valve	Natural Gas Control Valve
I-100	Injector	Steam Injector
C-100	Column	Stripping Column
S-100	Splitter	Recycle Splitter
M-100	Measurement	Surge Tank Level Meter
M-101	Measurement	Sour Water Flow Meter
M-102	Measurement	pH Meter 1
M-103	Measurement	pH Meter 2
M-104	Measurement	Humidity Meter
M-105	Measurement	Thermocouple
M-106	Measurement	Concentration Meter
LC	Level Controller	Level P-Control System
RC	Recycle Controller	Low-Flow Recycle Controller
VC   CP	Valve Control Computer	Natural Gas Control Valve Computer
TC	Temperature Controller	Heater Control System
HC	Humidity Controller	Steam Control System



**Figure 15.3:** 3D Model of Air Stripping Process. (Paint 3D). The orange air stream enters from the lower right, passes through the blower, heater, meets the grey steam stream at the injector, enters the bottom of the column, and exits the top of the column. The blue water stream enters from the left, passes through the surge tank, then, driven by gravity, meets a thin blue acid stream coming from the acid storage tank. The mixture flows downhill to the pump, then through the heater, then up to enter the top of the column. The water exits the bottom rear of the column and is split into a recycle stream back to the surge tank, and the product sweet water which flows to the right out of the diagram.

Section 16

# **Process Description**

The Process Flow Diagrams (PFDs) for each stripping agent case in the previous section (Figures 15.1 and 15.2) are nearly identical with respect to the sour water's path to the column. There are six measurement devices in the PFD, and each represent a set of duplicate measurement devices. They are duplicate to ensure against complications that arise if a device experiences drift or any type of malfunction, and to allow the system to continue to operate while the faulty device is replaced. With the exception of the pipe for Stream 6 which climbs 60 feet from ground-level to the top of the column, pressure drop through pipes is assumed to be negligible because the efficient layout of the operation minimizes pipe lengths and maximize gravity-driven flow (Figure 15.3). The following subsections refer to equipment and streams diagrammed in Figures 15.1 and 15.2, quantified in Tables 15.1 and 15.3, and described in Tables 15.2 and 15.4.

### **Section 16.1: Sour Water Feed (S1 and S2)**

The sour water feed enters the system from the refinery in Stream 1, where the average flow rate is 37.5 GPM (Appendix: A.1.3), average ammonia concentration is 1650 ppm, hydrogen sulfide concentration is 5 ppm, the temperature is 80°F, and the pressure is just above atmospheric at 15 psia. The sour water enters a surge tank, T-100 (see 18.1.1), which serves to dampen any spikes in flow rate or ammonia concentration. The surge tank has a capacity of 2500 gallons, large enough for one hour of holdup at average flow. The surge tank is also where the raffinate recycle stream is returned when it is activated. The surge tank has a level meter, M-100, with a level controller, LC (see 23.2.1), that controls the control valve, V-100, which alters the flow rate of the exit stream of the surge tank, Stream 2.

Stream 2 passes through the control valve, V-100, then through the flow meter, M-101. The measurement is transmitted to the recycle controller, RC (see 23.2.2), which diverts

a portion of the raffinate back to the surge tank if the sour water flow rate falls below 30 GPM. This flow meter measurement is also transmitted to the blower control computer (see 18.2.4, 23.2.3) for air stripping (and the valve control computer (see 18.3.4, 23.2.4) for natural gas stripping), which determines of amount of stripping agent needed for a given flow rate and composition of sour water.

A small portion of Stream 2 is diverted to flow through pH meter 1, M-102, before being returned to the main portion of the stream. Like the flow meter, the pH meter 1 transmits its measurement to the blower control computer (or valve control computer). This pH meter is the functional equivalent of a concentration meter. Since the only compositional variable in the sour water feed is ammonia, a basic component, the concentration of ammonia in the sour water can be directly correlated to the pH of the sour water (Table 16.1). A pH meter was chosen rather than a concentration meter based on the dead time associated with each type of unit. A concentration meter, usually a chromatograph, has a dead time on the order of minutes to tens of minutes, while the Yokogawa pH Meter apparatus in our process has a delay time of approximately 4 seconds (Appendix: A.4.1).<sup>10</sup> This negligent dead time greatly enhances the efficacy of the main control system of the blower control computer (or valve control computer).

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<sup>10</sup> Leach, Connor T, and Michael Dowdy. "PH Meter Delay Time for Step Input." 13 Mar. 2018. Michael is a sales representative for Cemtech Energy Controls, Inc., the Philadelphia sales representative company for Yokogawa Corporation of America.



**Table 16.1:** Correlation Between pH and Ammonia Concentration

Measured pH (M-102)	Ammonia Conc. [ppm]	Measured pH (M-102)	Ammonia Conc. [ppm]
5.412	0		(cont.)
10.339	100	11.051	1750
10.525	200	11.082	2000
10.628	300	11.110	2250
10.754	500	11.134	2500
10.852	750	11.156	2750
10.920	1000	11.176	3000
10.973	1250	11.195	3250
11.015	1500	11.212	3500

### Section 16.2: Mixing, Heating, and Pressurizing Sour Water and Acid (S3 S4)

Stream 2 is then mixed together with Stream 3 in the 400-gallon mixing tank, T-102 (see 18.1.3). Stream 3 is 33% by weight sulfuric acid in water, and has a low fixed flow rate of 1.8 lb/hr for air stripping (1.65 lb/hr for natural gas stripping) (Appendix: A.1.5). Stream 3 comes from the 200-gallon acid storage tank, T-101 (see 18.1.2), which is large enough to hold a 5-week supply of acid solution, and is restocked monthly. The mixing tank is sized for a 10-minute holdup at average flows, and is agitated to ensure the small amount of acid is well-mixed in the sour water before the homogenous stream moves on to the column as Stream 4.

Stream 4 leaves the mixing tank and a small diversion passes through pH meter 2, M-103, before being returned to the rest of the stream. This pH meter records the pH of the stream that will enter the column without undergoing any additional chemical changes. Stream 4 then enters the sour water pump, P-100 (see 18.1.4). The pump has an outlet pressure of 55 psia to provide enough pressure for the sour water to climb 60 feet to the top of the column, overcome the friction of the long vertical pipe, and to enter the column at 25 psia.

The sour water pump outlet, Stream 5, enters the natural gas burning fired heater. This sour water heater, F-100 (see 18.1.5), heats the sour water to the column inlet specification of 190°F. Stream 5 enters above the top tray, tray 1, of the stripping column, the details of which are discussed in Section 16.6

### Section 16.3: Air as Stripping Agent (S7 S8)

Stream 7 is the feed stream of the stripping agent: air in Figure 15.1 and natural gas in Figure 15.2. Since Stream 7 and the equipment unit that controls its flow rate (B-100 for air and V-101 for natural gas) are the most different between air and natural gas stripping, each will be described separately.

Stream 7 represents atmospheric air in Philadelphia, PA. Atmospheric air in this region annually fluctuates between 0°F and 100°F, and between 0 and 4 percent water vapor by mass. Philadelphia's mean annual temperature is 56°F.<sup>11</sup> The air is pulled into the system by a screened blower, B-100 (see 18.2.12), which is housed inside the temperature-controlled facility of the stripping operation. The indoor temperature of the facility is 70°F, so the air in the blower is assumed to be 70°F as well, since this is only 14°F higher than the annual average. A blower was chosen instead of a fan because a fan cannot generate the needed outlet pressure, and a compressor would be more expensive than a blower for the same pressure increase (Appendix: A.4.5).<sup>12</sup> In the ASPEN simulations, air is modeled as 79% nitrogen and 21% oxygen by mole, rather than "Air," so ASPEN could accurately calculate phase and dissolution chemistry. The

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<sup>11</sup> "Historic Average, Philadelphia, Pennsylvania." *Intellicast - Philadelphia Historic Weather Averages in Pennsylvania (19113)*, TWC Product and Technology, LLC, 2018, [www.intellicast.com/Local/History.aspx?location=USPA1276](http://www.intellicast.com/Local/History.aspx?location=USPA1276).

<sup>12</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

blower pulls in enough air to effectively strip the sour water leaving the surge tank; the amount of which is explicitly calculated as a direct function of sour water flow rate and ammonia concentration by the blower control computer (see 18.2.4). The blower pressurizes the air to 35 psia, the column inlet specification, and feeds it into the fired air heater, F-101. The blower must come before the heater in the air feed stream because the air must have a pressure gradient to flow through the heater.

#### **Section 16.4: Natural Gas as Stripping Agent (S7 S8)**

Stream 7 represents utility natural gas at the indoor temperature of 70°F, and an assumed pressure of 500 psig.<sup>13</sup> This pressure is too high to feed into our system, and since we need a valve to control the amount of natural gas fed to our system, a pressure drop from 514.7 psia to 35 psia was specified across the valve. This decrease in pressure leads to a higher volumetric flow rate, and decreases the temperature from 70°F to 42°F (Appendix: A.5.1). The utility natural gas is assumed to be 100% methane, with a negligibly small concentration of t-butyl mercaptan added by the utility company as a safety measure, so the gas can be smelled if there is a leak. The natural gas control valve, V-101 (see 18.3.1), allows enough natural gas to effectively strip the sour water leaving the surge tank; the amount of which is explicitly calculated as a direct function of sour water flow rate and ammonia concentration by the valve control computer (see 18.3.4). The natural gas leaves the natural gas control valve as Stream 8. The natural gas is depressurized before being heated to mitigate safety concerns, i.e. minimizing the length of piping that has to handle 500 psig natural gas and avoid feeding high pressure natural gas to a heater.

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<sup>13</sup>“Natural Gas – From Wellhead to Burner Tip.” *NaturalGas.org*, NaturalGas.Org, 20 Sept. 2013, [naturalgas.org/naturalgas/](http://naturalgas.org/naturalgas/).

### Section 16.5: Heating the Stripping Agent (S9 S10 S11)

Stream 8 is the pressurized air being fed to the air heater, F-101 (see 18.2.2), for air stripping (and is the de-pressurized natural gas being fed to the natural gas heater, F-101 (see 18.3.2)). The air heater heats the stream to 158°F for air stripping (and 180°F for natural gas stripping), which is lower than column inlet specification temperature. This is because the addition of 50 psig, 300°F utility steam helps to heat the mixture to the specified 190°F (Appendix: A.1.2). Stream 9, the heated gas, is injected with 30 psig steam from Stream 10 by the steam injector, I-100. The steam retains most of the heat energy through the injection, but its higher initial pressure does not significantly contribute to the gas stream. The stripping agent streams are heated before the steam is added so the gas is hot enough to be above the saturation temperature of 10% water vapor.<sup>14</sup> The reason water vapor must be added to the stripping agent is because the high temperatures in the column, as well as the large amount of gas in contact with the sour water, led to the vaporization of a large amount of sour water. This had the effect of both concentrating the contaminants in the raffinate, since there was less water to dissolve them in, and, more importantly, significantly cooling the column by the heat of vaporization of all the water that had undergone a phase change. To minimize the effect of sour water vaporizing, we applied Le Chatelier's Principle and added water vapor to our stripping agent before it entered the column, which lessened the amount of sour water that could be vaporized. This allowed the column to be operated at a higher temperature, and to effectively strip the contaminants to the required specifications.

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<sup>14</sup> Engineering ToolBox, "Water Vapor and Saturation Pressure in Humid Air." *Water Vapor and Saturation Pressure in Humid Air*, 2004, [www.engineeringtoolbox.com/water-vapor-saturation-pressure-air-d\\_689.html](http://www.engineeringtoolbox.com/water-vapor-saturation-pressure-air-d_689.html).

The humid stripping agent, Stream 11, passes by a humidity meter, M-104, which transmits the measurement to the humidity controller, HC (see 23.2.5). The humidity controller controls how much steam is injected into Stream 9 to maintain the humidity of Stream 11 at 10% by mass. Stream 11 also passes through a thermocouple, M-105, which transmits its measurement to the temperature controller, TC (see 23.2.6). The temperature controller controls the fired heater F-101 to maintain the temperature of Stream 11 at 190°F. The stripping agent leaves the thermocouple and enters the stripping column as Stream 12.

The potential atmospheric humidity of the incoming air will not be an issue for the steam injection humidification process. The saturation temperature for 10% water vapor in air is 115°F,<sup>15</sup> which is 9°F higher than Philadelphia's record high temperature of 106°F, set in 1918. This means that the atmospheric water vapor concentration will always be lower than the amount specified to enter the column, and the feedback humidity control system (23.2.5) will add enough steam to the fed air stream to reach the desired 10% specification no matter the humidity of the incoming air.

### Section 16.6: Feed and Effluent to Stripping Column (S6 S12 S13 S14)

The stripping column, C-100 (see 18.2.3 and 18.3.3), is the primary unit operation of the sour water stripping operation. The column has 20 Trays for air stripping, (and 17 trays for natural gas stripping), and was sized independently for each case. For both cases, a turndown capability of 60% is assumed, as well as a Murphree Tray Efficiency of 25%.<sup>16 17</sup> The column was sized to be able to handle the maximum flow rate of 50 GPM, and a turndown capability of 60% allows

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<sup>15</sup> Engineering ToolBox, "Water Vapor and Saturation Pressure in Humid Air." *Water Vapor and Saturation Pressure in Humid Air*, 2004, [www.engineeringtoolbox.com/water-vapor-saturation-pressure-air-d\\_689.html](http://www.engineeringtoolbox.com/water-vapor-saturation-pressure-air-d_689.html).

<sup>16</sup> Frederick, Andrew E, and Leonard Fabiano. "Column Design in ASPEN." 8 Mar. 2018. Leonard is an adjunct Professor at the University of Pennsylvania

<sup>17</sup> Hatcher, Nathan, and Ralph Weiland. "Reliable design of sour water strippers." *Petroleum Technology Quarterly* 17.4 (2012): 83.

the column to operate without tray weeping at 30 GPM, the lowest flow rate the system is expected to receive under normal operation. The sour water in Stream 6 is introduced to the column above the top tray, and the stripping agent in Stream 12 is added on the bottom tray. The column effluents are the contaminated stripping agent, and the sweeter water, purified to the specifications of less than 20 ppm ammonia and 0.1 ppm hydrogen sulfide.

The gaseous stripping agent leaves the top of the Stripping Column as Stream 13, the extract. The extract is comprised of the initial stripping agent and water vapor, as well as additional water vapor from evaporated sour water, and the stripped contaminants including most of the ammonia and hydrogen sulfide, and all of the propane.

In the case of natural gas stripping, the contaminated natural gas extract, Stream 13, would be sold back to the main utility feed of natural gas to the refinery. The average annual natural gas consumption of a refinery on the east coast (EIA PADD 1) was 5,813,400,000 SCFY in 2016 (Appendix: A.1.1).<sup>18</sup> The natural gas stripping process for sour water uses 1,161,000,000 SCFY (Appendix: A.1.1). One fifth of the natural gas utility purchased by the refinery would need to be diverted to strip the sour water. The stripping process loses 0.0019% (21,800 SCFY) of natural gas to the raffinate sweet water, but the remaining 99.9981% is recoverable (Table 15.3). The extract from the natural gas stripping process is comprised of primarily natural gas, 82.7% by mass, and also contains 17.7% water, 0.167% ammonia (1670 ppm) and 0.000495% hydrogen sulfide (5 ppm) (Table 15.3). This gas is at a significantly lower pressure (2.3 psig) than the refinery feed of natural gas (500 psig). Assuming eductors or injectors can be used to return this extract stream to the feed natural gas, against the pressure gradient, and that the price at which the

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<sup>18</sup> U.S. Energy Information Administration. "Fuel Consumed at Refineries." *East Coast (PADD 1) Fuel Consumed at Refineries*, U.S. Department of Energy, 21 June 2017, [www.eia.gov/dnav/pet/pet\\_pnp\\_capfuel\\_dcu\\_r10\\_a.htm](http://www.eia.gov/dnav/pet/pet_pnp_capfuel_dcu_r10_a.htm).

refinery will buy back the natural gas does not depend on pressure, returning the extract natural gas to the refinery feed is an effective way to make the natural gas useful and redistributable to the refinery, and to dilute the contaminants to a lower level to be burned in fired heaters. If the column extract is returned to the natural gas feed, the water concentration would be diluted to 3.42%, the ammonia would be diluted to 334 ppm, and the hydrogen sulfide would be diluted to 0.99 ppm.

This concentration of water vapor in the natural gas is appropriate for combustion. The combustion of methane in air is stable up to a 15% water vapor content in the air, which is introduced in a 19:1 ratio to natural gas.<sup>19</sup> This corresponds to a 14.25% water vapor presence in the mixture, whereas our natural gas extract (before dilution) would lead to a mixture water vapor content of 1.25%. Therefore, the humidity of the extract natural gas stream is not an obstacle to recycling it for use as fuel.

In the case of air stripping, rather than being released to the atmosphere, the extract can also be returned to the refinery as preheated air to be consumed in natural gas burning fired heaters, which requires a natural gas-to-air ratio of 19:1.<sup>20 21</sup>

The stripped sweeter water exiting the bottom of the stripping column, Stream 14, and a concentration meter, M-106. This concentration meter measures the concentrations of every component present in the sour water, especially the ammonia and hydrogen sulfide and their dissociative counterparts. This meter is not part of the control system for the column, because to maintain the specified purities 100% of the time, a feedback control system with a large dead time chromatograph would not be adequate. The concentration meter serves to ensure the specifications

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<sup>19</sup> Nakhamkin, M., et al. *Combustion Studies of Natural Gas and Syn-Gas with Humid air*. Technical report, EPRI, Palo Alto CA, USA, 1994.

<sup>20</sup> Frederick, Andrew E, and Tyler McDevitt. "Sour Water Process Engineer Consultation." 12 Apr. 2018. Tyler is a process engineer at Phillips 66 refinery.

<sup>21</sup> Methane MDSD.

are being met, and the results will be monitored by the control room operator, and a computer alarm system, which will take action to fix any problems that arise if the specifications cease being met.

The sweet water of Stream 14 passes through a splitter valve, S-100, which is usually not in use. The project specifications indicate that the expected incoming sour water flow rate will range from 30 to 50 GPM, with two-day periods of 20 GPM low-flow prior to, and following, annual refinery shutdown. During the periods of low-flow, and any time the flow rate unexpectedly drops below 30 GPM, the recycle controller will have the splitter recycle enough of the raffinate to the surge tank, Stream 15, to maintain a minimum column water flow rate of 30 GPM.

Stream 16 is the relatively sweet water effluent from the process. The stripped water has low enough concentrations of all contaminants to be discharged into the Delaware River, since the Philadelphia refinery is located along it. Other options for the sweet water include sewer discharge, or recycling for other refinery uses, i.e. boiler feed water (BFW) or desalting operations.



Section 17

# **Energy Balance and Utility Requirements**

### **Section 17.1: Heat Integration**

Heat integration was not necessary for this project. The reason for this is because, for the natural gas case, the effluent gas stream (Stream 13) is going to be sent back to the refinery's natural gas feed to the furnace to be burnt. If this stream was to be used to help heat the influent gas stream from 80°F (Stream 5) to 190°F (Stream 6) required for stripping, its temperature would decrease and require even more heat to reach the required temperature for combustion in the furnace. Because no heat exchanger is 100% efficient, reheating Stream 13 would require more energy and increase utility and operating costs. Additionally, heat integration would require the capital cost of a heat exchanger, an unnecessary cost for an inferior design. For that reason, we did not think it was a good idea to do a heat integration on this part. This same reasoning applies for the effluent air stream in the air stripping process since it is also being recycled to the furnaces.

### **Section 17.2: Stripping Efficiency**

As mentioned in Section 13, in order to increase the effectiveness of stripping, the sour water feed stream (Stream 6) and air/ natural gas stream (Stream 9) were evaluated. It was found that at extreme conditions, specifically low flow rate of sour water coupled with high concentration of ammonia, air alone or natural gas alone could not effectively strip ammonia and hydrogen sulfide from sour water. In addition to this, there was a lot of heat lost in the column due to the heat of vaporization of water in sour water evaporating to the air/ natural gas stream. For that reason, we decided to add 10 mole% water to the incoming air stream and natural gas stream to prevent much of the evaporation, making the column much warmer throughout (137°F for the air stripping process and 140°F for the natural gas stripping process in Stream 14). The addition of 10 mole% water also made the stripping process much more efficient because it reduced the

required amount of air for stripping by 71.3% and the required amount of natural gas for stripping by 62.2%.

### Section 17.3: Utility Requirements

Table 17.1 and Table 17.2 show details of utility requirements and electricity for air stripping process and natural gas stripping process respectively.

**Table 17.1:** Utility and Electricity Requirements for Air Stripping Process

Utility	Equipment	Quantity (per hr)	Quantity (per yr)
Steam @50 psi	I-100	1665	13.32 MM
	<b>Total (lb)</b>	<b>1665</b>	<b>13.32 MM</b>
Natural Gas	F-100	354.59	2.84 MM
	F-101	73.32	0.59 MM
	<b>Total (lb)</b>	<b>427.91</b>	<b>3.48 MM</b>
Electricity	B-100	23.32	0.187 MM
	P-100	1.61	0.01288 MM
	<b>Total (Kwh)</b>	<b>24.9</b>	<b>0.019988 MM</b>

**Table 17.2:** Utility and Electricity Requirements for Natural Gas Stripping Process

Utility	Equipment	Quantity (lb/hr)	Quantity (lb/yr)
Steam @50 psi	I-100	1665	13.32 MM
	<b>Total (lb)</b>	<b>1665</b>	<b>13.32 MM</b>
Natural Gas	F-100	359.54	2.84 MM
	F-101	87.9	0.70 MM
	<b>Total (lb)</b>	<b>442.49</b>	<b>3.54 MM</b>
Electricity	P-100	1.61	0.01288 MM
	<b>Total (Kwh)</b>	<b>1.61</b>	<b>0.01288 MM</b>

Section 18

# Equipment List and Unit Descriptions

The process unit descriptions will be detailed in four sections: sour water specific, air specific, natural gas specific, and minor equipment. The sour water specific section contains the equipment that will be designed identically for the sour water process regardless of the stripping agent that is used. The air specific section contains the equipment necessary if air is the stripping agent. The natural gas specific section is laid out the same way. Finally, the minor equipment section contains a list of miscellaneous valves, devices, and other control system related equipment.

### **Section 18.1: Sour Water Specific Equipment (Figures 15.1 and 15-2)**

#### **Section 18.1.1: Sour Water Surge Tank: T-100**

<i>Type:</i>	Open storage tank
<i>Material:</i>	Fiberglass
<i>Bare Module Cost:</i>	\$55,876.00
<i>Specification Sheet:</i>	Section 19.1 and 19.2

The sour water surge tank was designed to reduce any fluctuation and variability in the inlet sour water feed flow rate and composition. Additionally, it was designed to enable the recycling of the raffinate during plant shut down. To ensure that all spikes in the inlet feed will be dampened, the tank was designed to hold 2500 gallons, or one hour's average worth of flow. The 2500 gallon capacity of the tank will ensure that the flow out of the tank, Stream 2, will be consistent in flow rate and composition, maximizing the effectiveness of the control system.

**Section 18.1.2: Acid Storage Tank: T-101**

<i>Type:</i>	Closed Storage Tank
<i>Material:</i>	316 Stainless Steel
<i>Bare Module Cost:</i>	\$1,977.00
<i>Specification Sheet:</i>	Section 19.1 and 19.2

The acid storage tank is designed to hold the 33.3% sulfuric acid solution that will be added at 1.8 lb/hr when air is used as the stripping agent and 1.65 lb/hr when natural gas is used as the stripping agent. These acid flow rates prime the streams to be stripped to the required raffinate conditions regardless of sour water flow rate. The steady acid flow rates also prevent the need for an acid control system. The tank is big enough to hold an entire bulk order of sulfuric acid so that it does not have to be stored on the facility floor.

**Section 18.1.3: Acid Mixing Tank: T-102**

<i>Type:</i>	Closed Tank
<i>Accessories:</i>	Agitator
<i>Material:</i>	316 Stainless Steel
<i>Bare Module Cost:</i>	\$29,597.00
<i>Specification Sheet:</i>	Section 19.1 and 19.2

The acid mixing tank is designed to ensure homogenous mixing of the sulfuric acid solution and sour water feed prior to entering the column. Doing so will reduce the pH of the sour water, which readjusts the composition of the sour water stream to be primed for stripping. Given that the average flow is 37.5 GPM, a capacity of 400 gallons will provide an average mixing time of around ten minutes, which will ensure a consistent outlet concentration in Stream 4. The 316 stainless steel is to prevent corrosion from the acid.

**Section 18.1.4: Sour Water Pump: P-100**

<i>Type:</i>	Centrifugal Pump
<i>Material:</i>	Stainless Steel
<i>Bare Module Cost:</i>	\$30,679.00
<i>Specification Sheet:</i>	Section 19.1 and 19.2

The sour water pump is designed to handle the maximum sour water flow rate of 50 GPM. The pump type is the industry standard centrifugal pump. The inlet pressure is 15 psia, and the outlet pressure is 55 psia, to provide enough pressure to pump the water through the heater, up 60 feet to the top of the column, and enter the column at 25 psia. The head necessary for this pressure increase is 92.6 ft. The construction material is stainless steel to avoid any corrosion from sour water contaminants. The calculated bare module cost of the sour water pump is \$30,679.00.

**Section 18.1.5: Sour Water Heater: F-100**

<i>Type:</i>	Fired Heater
<i>Operating P:</i>	55 psia
<i>Material:</i>	Stainless Steel
<i>Bare Module Cost:</i>	\$378,824.00
<i>Specification Sheet:</i>	Section 19.1 and 19.2

The sour water heater is designed to handle a maximum of 25,036 lb/hr of sour water. Raising the temperature of this stream from 80°F to 190°F takes a maximum heat duty of 2,753,960 Btu/hr. The type of heater is a fired heater. The operating pressure is 55 psia, the pressure of the sour water stream. The construction material is stainless steel, to avoid any corrosion from the sour water contaminants. The heater will be shop fabricated. The bare module cost of the sour water heater is \$378,824.00.

## Section 18.2: Air Specific Equipment (Figure 15.1)

The process equipment designs for the stripping agent feed streams, as well as the stripping column itself, depend intimately on the stripping agent used. For the air stripping process, the size of the blower, heater, and stripping column were optimized together to minimize the combined bare module cost, e.g. a column with more trays would be more expensive, but require less air leading to a less expensive blower and air heater. This optimization was based on the maximum sour water flow rate and ammonia concentration, and accordingly at the maximum air flow rate, because this is the highest output the equipment will need to be designed to handle.

### Section 18.2.1: Blower: B-100

<i>Type:</i>	Centrifugal (turbo) Blower
<i>psia in:</i>	15
<i>psia out:</i>	35
<i>Material:</i>	Aluminum
<i>Bare Module Cost:</i>	\$162,083.00
<i>Specification Sheet:</i>	Section 19.1

The blower for the air stripping system is designed to accommodate a maximum flow rate output capacity of 4036 cu.ft. per minute. The inlet pressure is 15 psia, and the outlet pressure is 35 psia. The material of construction is aluminum because this is the least expensive option, and is sufficient for the purpose of pulling atmospheric air into the system. The type of blower is the industry standard centrifugal blower. A screen on the inlet side of the blower will prevent large contaminants, such as birds, from entering the process air feed. The calculated bare module cost of the blower is \$162,083.00.



**Section 18.2.2: Air Heater: F-101**

<i>Type:</i>	Fired Heater
<i>Operating P:</i>	35 psia
<i>Material:</i>	Cr-Mo Alloy Steel
<i>Bare Module Cost:</i>	\$87,199.00
<i>Specification Sheet:</i>	Section 19.1

The heater for the air stripping system is designed to accommodate a maximum flow rate of 33,793 lb/hr. This amount of air entering at 70°F and being heated to 158°F requires a maximum heat duty of 542,901 Btu/hr. The heater type is a fired heater, as this was the least expensive option to choose from in Seider et al.<sup>22</sup> The operating pressure of the heater is 35 psia. The Cr-Mo Alloy Steel was chosen to be the material over stainless steel because the heater does not have to be resistant to corrosion and the alloy steel is less expensive. The fabrication method of the heater is at the shop. The calculated bare module cost of the air heater is \$87,199.00.

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<sup>22</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

**Section 18.2.3: Stripping Column: C-100**

Trays:		Column:	
<i>Number:</i>	20	<i>Height/Diameter Ratio:</i>	10.64
<i>Efficiency:</i>	25%	<i>Height:</i>	50 ft
<i>Type:</i>	Sieve	<i>Diameter:</i>	4.701 ft
<i>Spacing:</i>	2 ft	<i>Turndown capability:</i>	60%
<i>Pressure drop:</i>	0.1 psi	<i>Pressure drop:</i>	1.9 psi
		<i>Bare Module Cost:</i>	\$738,056.00
		<i>Material:</i>	316 Stainless Steel
		<i>Specification Sheet:</i>	Section 19.1

The column was optimized to strip 20-50 GPM of sour water at initial compositions between 300-3000 ppm down to an outlet concentration 20 ppm. Although traditional sour water strippers use steam and have a reboiler and condenser, air is already in the gaseous phase and is not compressible at reasonable temperatures. To optimize the column, a variety of parameters were tested and their impact was observed on the extent of the stripping process. The parameters and their effects are listed in Table 18.1 below.

**Table 18.1:** Preliminary Analysis of Stripping Parameters. The parameters were qualitatively tested through ASPEN and their costs to adjust were roughly determined. The parameters with good stripping value (high impact on stripping and a low cost to adjust) were highlighted in green and those with medium value were highlighted in yellow.

Parameter		Impact on Stripping Effectiveness	Cost to Adjust
Air/Methane	Flow Rate	High	Medium
	Temperature	Medium	Medium
	Pressure	Low	Low
Water	Temperature	High	Medium
	Pressure	Low	Low
Stripping Column	Number of Stages	High	High
	pH	High	Low

By adjusting one variable at a time and keeping the remainders constant, the most impactful variables on the stripping process were determined and labeled as “High” in Table 18.1. The influence of these variables on the process through the amount of ammonia stripped can be seen in the figures in the Appendix (A.2.1). To optimize the column, it was essential to minimize parameters with a high cost to adjust and prioritize parameters with a large impact on stripping effectiveness and a low cost to adjust (Appendix: A.2.1). For example, increasing the number of stages greatly increased the effectiveness of the column but also had the greatest cost associated with doing so by far. Therefore, the number of stages was minimized while cheaper parameters like the stripping agent flow rate and water temperature were increased.

All of the above parameters greatly affected the amount of ammonia that could be stripped from the process but had little impact on the amount of hydrogen sulfide that could be stripped. As it stood, the sweeter water still had a concentration of 2.5 ppm which was well above the 0.1 ppm limit. This is because the large majority of the hydrogen sulfide in the sweet water was in its dissociated conjugate base in the form of  $\text{HS}^-$ . Ions in water cannot be stripped because they have too strong of interactions with polar water molecules. Therefore it was realized that stripping more hydrogen sulfide from the sour water required a lower pH. While a lower pH increases the amount of hydrogen sulfide that can be stripped, it converts ammonia to its conjugate acid, ammonium, and reduces the amount of ammonia that could be stripped. Determining the optimal pH of the sour water required a careful balance to ensure that both species could be stripped in their undissociated form and reach the outlet concentration requirements.

From the literature and the industrial consultants, it was determined that the Murphree Tray Efficiency for a stripping column is 25%.<sup>23</sup> The efficiency is less than 100% because the liquid and vapor phases on each tray are not in contact long enough to reach thermodynamic equilibrium. Trays were selected over column packing because ASPEN cannot accurately predict the size of a column for packing. Sieve trays were selected as opposed to bubble cap trays and valve trays for a couple of reasons. First, sieve trays are less expensive than both bubble cap trays and valve trays. Additionally, sieve trays are the easiest to clean. The spacing between trays was chosen to be the commercial standard of 2 feet. The height of the column, number of trays multiplied by the tray spacing, was 40 feet. However, 5 feet above tray one and 5 feet below tray two were added to the column to accommodate the addition and removal of the streams. The diameter of the column was given as 4.7 feet and the 60% turndown capacity of 50 GPM means the minimum standard flow is 30 GPM. The thickness was chosen to be 0.3125 inches because an extra 0.125 inches was added to the walls to account for corrosion, and the next largest thickness of the column commercially available was 0.3125 inches

The top of the column was set to 17 psia and the pressure drop per stage was suggested to be 0.1 psi. The incoming water feed at the top of the column was set to 25 ppm, and the incoming stripping agent at the bottom of the column was set to 35 ppm. The difference between the two incoming streams is well above the 1.9 psi pressure drop that the column will experience. The calculated bare module cost is \$738,056.00 and the column is made from 316 Stainless Steel.

An example of an ASPEN simulation used to optimize the air stripping column can be found in the Appendix (A.5.2).

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<sup>23</sup> Frederick, Andrew E, and Leonard Fabiano. "Column Design in ASPEN." 8 Mar. 2018. Leonard is an adjunct Professor at the University of Pennsylvania

### Section 18.2.4: Blower Control System Computer: BC | CP with Equation

The blower control computer is the key to stripping the sour water to the required specifications. The blower control computer determines how much air is needed to strip sour water of a given flow rate and ammonia concentration. A more detailed description of the control system is given in Section 23.2.3. Equation 18.1 was formulated to calculate the required amount of air to strip the sour water. To ensure that enough air is used, the equation has a small overshoot buffer, and because the specifications in ASPEN were for 19 instead of 20 ppm ammonia (plus ammonium). Below is Equation 18.1:

$$V = \left( \left( \sqrt{C} * \frac{FF}{24} + \frac{(15000-FF)}{12.5} - 330 * \left( \frac{C}{300} \right)^{1.5} + 555 + (FF - 20000) * 0.026 \right) * \left( \frac{300}{C} \right)^{0.2} + \left( \frac{C}{300} \right)^{\frac{1}{3}} + \left( \frac{29}{FF} * \frac{C}{4} \right)^{19.15} + \left( \left( \frac{15000}{FF} \right)^{0.1} * \frac{C}{3} \right) + \frac{16000-FF}{1.25} + \left( \frac{300}{C} \right)^3 * 58 * \frac{FF-14000}{115} + abs \left| \frac{FF-19100}{4.3} \right| \right) * 0.8802,$$

where **V** is the air flow required in lb/hr, **C** is the concentration of ammonia in ppm, and **FF** is the feed sour water flow rate in lb/hr (or 498.65\*GPM at flowmeter conditions). This feed-forward control equation will be utilized by the blower control computer to set the blower to the appropriate specification based on the sour water flow rate.

**Section 18.3: Natural Gas Specific (Figure 15-2)**

As was the case for air, the optimization of the natural gas stripping process was performed on the heater and stripping column to minimize the combined bare module cost. This optimization was based on the maximum sour water flow rate and ammonia concentration and the maximum natural gas flow rate, as the equipment needs to be designed to handle the maximum process output.

The natural gas heater is significantly more expensive than the air heater, \$195,927.00 vs \$87,199.00, but the natural gas control valve has no bare module cost compared to the \$162,083.00 for the air blower. The natural gas stripping column is less expensive than the air stripping column, \$680,792.00 vs \$738,056.00. The total bare module cost of the natural gas specific units is \$876,719 and the total bare module cost of the air specific units \$987,388. This difference shows that the natural gas stripping process has a lower capital cost than the air stripping process, but the true economic comparisons are the NPV calculations in Section 24, which incorporate capital costs, operating costs, utility costs, depreciation costs, and more.

**Section 18.3.1: Control Valve: V-101**

While the natural gas stripping process does not include a blower, it does include a large control valve which allows the necessary amount of natural gas into the system, and reduces the pressure from 500 psig to 35 psia. The cost of the control valve is accounted for in the pricing factors of the rest of the equipment.

**Section 18.3.2: Natural Gas Heater: F-101**

<i>Type:</i>	Fired Heater
<i>Operating P:</i>	35 psia
<i>Material:</i>	Cr-Mo Alloy Steel
<i>Bare Module Cost:</i>	\$195,927.00
<i>Specification Sheet:</i>	Section 19.2

The heater required for the natural gas stripping system is designed to handle a maximum flow rate of 23,054 lb/hr. This amount of natural gas entering at 42°F and being heated to 180°F requires a maximum heat duty of 1,522,641 Btu/hr. The heater type is a fired heater, the least expensive option recommended in Seider et al.<sup>24</sup> The operating pressure of the heater is 35 psia. The material of construction is Cr-Mo Alloy Steel, the less expensive option. The fabrication method is shop fabrication. The calculated bare module cost of the natural gas heater is \$195,927.00.

**Section 18.3.3: Stripping Column: C-100**

<i>Trays:</i>		<i>Column:</i>	
<i>Number:</i>	17	<i>Height/Diameter Ratio:</i>	9.75
<i>Efficiency:</i>	25%	<i>Height:</i>	44 ft
<i>Type:</i>	Sieve	<i>Diameter:</i>	4.513 ft
<i>Spacing:</i>	2 ft	<i>Turndown capability:</i>	60%
<i>Pressure drop:</i>	0.1 psi	<i>Pressure drop:</i>	1.6 psi
		<i>Bare Module Cost:</i>	\$680,792.00
		<i>Material:</i>	316 Stainless Steel
		<i>Specification Sheet:</i>	Section 19.2

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<sup>24</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

The optimization analysis of the column with natural gas as the stripping agent was performed in the same manner as that of the column with air as the stripping agent. The parameters in Table 18.1 had the same effect on the stripping process and the same costs associated with them. In this case, because natural gas is a better stripping agent than air, the number of trays was lowered even further to 17.

As was the case with the air stripper, it was determined that the Murphree Tray Efficiency for a stripping column is 25%. The efficiency is less than 100% because the liquid and vapor phases on each tray are not in contact long enough to reach thermodynamic equilibrium. Trays were selected over column packing because ASPEN cannot accurately predict the size of a column for packing. Sieve trays were selected as opposed to bubble cap trays and valve trays for a couple of reasons. First, sieve trays are less expensive than both bubble cap trays and valve trays. Additionally, sieve trays are the easiest to clean. The spacing between trays was chosen to be the commercial standard of 2 feet. The height of the column, number of trays multiplied by the tray spacing, was 34 feet. However, 5 feet above tray one and 5 feet below tray two were added to the column to accommodate the addition and removal of the streams. The diameter of the column was given as 4.51 feet and the 60% turndown capacity of 50 GPM means the minimum standard flow is 30 GPM.

The top of the column was set to 17 psia and the pressure drop per stage was suggested to be 0.1 psi. The incoming water feed at the top of the column was set to 25 ppm, and the incoming stripping agent at the bottom of the column was set to 35 ppm. The difference between the two incoming streams is well above the 1.9 psi pressure drop that the column will experience. The calculated bare module cost is \$680,792.00 and the column is made from 316 Stainless Steel.



An example of an ASPEN simulation used to optimize the natural gas stripping column can be found in the Appendix (A.5.3).

#### Section 18.3.4: Valve Control System Computer: VC | CP with Equation

The valve control computer is the key to stripping the sour water to the required specifications. The valve control computer determines how much natural gas is needed to strip sour water of a given flow rate and ammonia concentration.

A more detailed description of the control system is given in Section 23.2.4. Equation 18.2 was formulated to calculate the required amount of natural gas to strip the sour water. To ensure that enough natural gas is used, the equation has a small overshoot buffer, and because the specifications in ASPEN were for 19 instead of 20 ppm ammonia (plus ammonium). Below is Equation 18.2:

$$V = \left( \left( \left( \frac{C*FF}{1500} + \frac{15000-FF}{12.5} - 330 * \left( \frac{C}{300} \right)^{1.5} + 330 + (1000 - C) * 6 * \left( \frac{FF-17200}{10000} \right) \right) + 6065 \right) * 0.96 - \left( \frac{15000}{FF} \right)^{1.5} * C * 5 + \frac{(900-C)*FF}{20000} - abs|1600 - C| * \left( \frac{FF}{27000} \right)^3 + \left( \frac{15000}{FF} \right)^4 * 3300 + \frac{C}{3} * \frac{25000}{FF} \right) * \frac{(14+\frac{300}{C})}{14.3},$$

where **V** is the natural gas flow required in lb/hr, **C** is the concentration of ammonia in ppm, and **FF** is the feed sour water flow rate in lb/hr (or 498.65\*GPM at flowmeter conditions). This feed-forward control equation will be utilized by the valve control computer to set the blower to the appropriate specification based on the sour water flow rate.

**Section 18.4: Minor Equipment**

Minor equipment that was incorporated but not fully designed include

- Level meter, controller, control valve
- Flowmeter and ph meter for main control system
- pH meter for post-acid
- Steam injectors
- Humidity meter and controller
- Thermocouple and controller
- Raffinate composition meter
- Splitter valve.

Section 19  
**Specification Sheets**

**Section 19.1: Specification Sheets for Air Stripping Process**

<b>Acid Storage Tank</b>				
<b>Identification:</b>	<b>Item</b>	<i>Acid Storage Tank (air)</i>		<b>Date:</b>
	Item No.	T-101(air)		<b>By:</b>
	No. required	1		17-Apr-18 Team 5
<b>Function:</b>	Store sulfuric acid before use			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Discharge (S3)</b>	<b>N/A</b>	<b>N/A</b>	<b>N/A</b>
Temperature(°F)	80.0	-	-	-
Pressure(psia)	15.0	-	-	-
Operating Volume Flow (cuft/hr)	0.0	-	-	-
Molar vapor fraction	0.0	-	-	-
Molar Flow (lbmol/hr)	0.073	-	-	-
Mass Flow (lb/hr)	1.8	-	-	-
Component Mass Flow (lb/hr)				
H <sub>2</sub> O	1.09	-	-	-
NH <sub>3</sub>	-	-	-	-
NH <sub>4</sub> <sup>+</sup>	-	-	-	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	-	-	-	-
H <sub>2</sub> S	-	-	-	-
HS <sup>-</sup>	-	-	-	-
S <sup>--</sup>	-	-	-	-
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>--</sup> )	-	-	-	-
C <sub>3</sub> H <sub>8</sub>	-	-	-	-
H <sub>3</sub> O <sup>+</sup>	1.20E-01	-	-	-
OH <sup>-</sup>	-	-	-	-
N <sub>2</sub>	-	-	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> <sup>-</sup>	5.88E-01	-	-	-
SO <sub>4</sub> <sup>--</sup>	0.0054	-	-	-
<b>Design Data:</b>				
Capacity	200 gal			
MOC:	Polyethylene			
Depth:	48"			
Diameter:	36" OD			
Wall	5/16"			
<b>Utilities:</b>	-			
<b>Comments and drawings:</b>	See Section 15, Figure 15.1 PFD for Air Stripping Process			

<b>Surge Tank</b>				
<b>Identification:</b>	<b>Item</b>	<i>Surge Tank (air)</i>		<b>Date:</b> 17-Apr-18
	Item No.	T-100(air)		<b>By:</b> Team 5
	No. required	1		
<b>Function:</b>	Dampen any spikes in flow rate and ammonia concentration			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Sour Water from Refinery ( S1)</b>	<b>Recycle Stream (S15)</b>	<b>Discharge (S2)</b>	<b>N/A</b>
Temperature(°F)	80.0	137.00	80.00	-
Pressure(psia)	15.0	18.80	15.00	-
Operating Volume Flow (cuft/hr)	37.5 (GPM)	-	37.5 (GPM)	-
Molar vapor fraction	-	-	-	-
Molar Flow (lbmol/hr)	1006.0	-	1006.0	-
Mass Flow (lb/hr)	18122.4	-	18122	-
Component Mass Flow (lb/hr)				
H <sub>2</sub> O	18092.00	-	18093	-
NH <sub>3</sub>	29.48	-	29.36	-
NH <sub>4</sub> <sup>+</sup>	0.442	-	0.58	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.94	-	29.94	-
H <sub>2</sub> S	8.08E-05	-	8.08E-05	-
HS <sup>-</sup>	0.088	-	0.088	-
S <sup>--</sup>	4.86E-05	-	4.86E-05	-
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>--</sup> )	0.0879	-	0.0879	-
C <sub>3</sub> H <sub>8</sub>	0.018	-	0.018	-
H <sub>3</sub> O <sup>+</sup>	1.06E-07	-	1.06E-07	-
OH <sup>-</sup>	0.372	-	0.372	-
N <sub>2</sub>	-	--	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> <sup>-</sup>	-	-	-	-
SO <sub>4</sub> <sup>--</sup>	-	-	-	-
<b>Design Data:</b>				
Size	2500 gal			
MOC:	Fiberglass			
<b>Utilities:</b>	-			
<b>Comments and drawings:</b>	See Section 15, Figure 15.1 PFD for Air Stripping Process			

<h2>Acid Mixing Tank</h2>				
<b>Identification:</b>	<b>Item</b> Item No. T-102(air) No. required 1	<i>Acid Mixing Tank (air)</i>	<b>Date:</b> 17-Apr-18 <b>By:</b> Team 5	
<b>Function:</b>	Mix sulfuric acid with sour water to reduce the pH			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Sour Water Feed (S2)</b>	<b>Acid Feed (S3)</b>	<b>Discharge (S4)</b>	<b>N/A</b>
Temperature(°F)	80.0	80.00	80.00	-
Pressure(PSIA)	15.0	15.00	15.00	-
Operating Volume Flow (cuft/hr)	37.5 (GPM)	0.023	37.5	-
Molar vapor fraction	0.0	0.0	0.0	-
Molar Flow (lbmol/hr)	1006.0	0.07	1006.1	-
Mass Flow (lb/hr)	18122.4	1.65	18124	-
Component Mass Flow (lb/hr)				
H <sub>2</sub> O	18092.00	1.09	18093	-
NH <sub>3</sub>	29.48	-	29.36	-
NH <sub>4</sub> <sup>+</sup>	0.44	-	0.58	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.92	-	29.94	-
H <sub>2</sub> S	8.08E-05	-	1.03E-04	-
HS <sup>-</sup>	0.088	-	0.088	-
S <sup>--</sup>	4.86E-05	-	3.90E-05	-
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>--</sup> )	0.088	-	0.088	-
C <sub>3</sub> H <sub>8</sub>	0.018	-	0.018	-
H <sub>3</sub> O <sup>+</sup>	1.06E-07	0.12	1.40E-07	-
OH <sup>-</sup>	0.37	-	0.29	-
N <sub>2</sub>	-	-	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	1.80E-09	-	-
HSO <sub>4</sub> <sup>-</sup>	-	0.588	1.50E-07	-
SO <sub>4</sub> <sup>--</sup>	-	0.0054	0.588	-
<b>Design Data:</b>				
Capacity	400 gal			
MOC:	Stainless Steel			
Depth:	46-1/2"			
Diameter:	52" ID			
<b>Utilities:</b>	412.24 lb/hr of natural gas			
<b>Comments and drawings:</b>	See Section 15, Figure 15.1 PFD for Air Stripping Process			

<b>Sour Water Pump</b>					
<b>Identification:</b>	<b>Item</b>	<i>Sour Water Pump</i>		<b>Date:</b>	<i>17-Apr-18</i>
	Item No.	P-100(air)		<b>By</b>	<i>Team 5</i>
	No. required	1			
<b>Function:</b>	Increase the pressure of the incoming sour water to the required pressure for stripping				
<b>Operation:</b>	Continuous				
<b>Materials handled:</b>	<b>Feed (\$4)</b>	<b>Discharge (\$5)</b>	<b>N/A</b>	<b>N/A</b>	
Temperature(°F)	190.0	190.00	-	-	
Pressure(psia)	35.0	25.00	-	-	
Pressure(psig)	20.3	10.30	-	-	
Vapor Fraction	1.0	0.00	-	-	
Molar Flow (lbmol/hr)	924.0	1387.95	-	-	
Volume Flow (cuft/hr)	183841.0	301.00	-	-	
Mass Flow (lb/hr)	25657.0	25000.00	-	-	
<b>Component Mass Flow (lb/hr)</b>					
H <sub>2</sub> O	18093.30	18093.3	-	-	
NH <sub>3</sub>	29.4	29.4	-	-	
NH <sub>4</sub> <sup>+</sup>	0.6	0.6	-	-	
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.94	29.9	-	-	
H <sub>2</sub> S	1.03E-04	0.0	-	-	
HS-	0.1	0.1	-	-	
S--	3.90E-05	0.0	-	-	
(H <sub>2</sub> S) + (HS-) + (S--)	0.0879	0.1	-	-	
C <sub>3</sub> H <sub>8</sub>	0.0	0.0	-	-	
H <sub>3</sub> O <sup>+</sup>	1.40E-07	0.0	-	-	
OH-	0.3	0.3	-	-	
N <sub>2</sub>	-	-	-	-	
O <sub>2</sub>	-	-	-	-	
CH <sub>4</sub>	-	-	-	-	
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-	
HSO <sub>4</sub> <sup>-</sup>	1.50E-07	0.0	-	-	
SO <sub>4</sub> <sup>--</sup>	0.6	0.6	-	-	
<b>Design Data:</b>					
Net Work	2.16523 Hp		Head	2 ft	
MOC:	Stainless Steel		Max Motor hp:	75 Hp	
Type:	Centrifugal Pump				
Orientation:	HSC				
shaft rpm:	3600				
Max. Flow (GPM)	50				
Head (ft-lbf/lb)	92.7483				
Pump Efficiency used:	0.39				
<b>Utilities:</b>	1.61461 KWh of electricity				
<b>Comments and Drawings:</b>	See Section 15, Figure 15.1 PFD for Air Stripping Process				

<b>Sour Water Heater</b>				
<b>Identification:</b>	<b>Item</b>	<i>Sour Water Heater</i>		<b>Date:</b>
	Item No.	F-100(air)		<i>17-Apr-18</i>
	No. required	1		<b>By</b>
				<i>Team 5</i>
<b>Function:</b>	Increase the temperature of the incoming sour water to the required temperature for stripping			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Feed (S5)</b>	<b>Discharge (S6)</b>	<b>N/A</b>	<b>N/A</b>
Temperature(°F)	190.00	190.00	-	-
Pressure(psia)	25.00	25.00	-	-
Pressure(psig)	10.30	10.30	-	-
Vapor Fraction	-	-	-	-
Molar Flow (lbmol/hr)	1387.95	1387.95	-	-
Volume Flow (cuft/hr)	301.00	37.5 (GPM)	-	-
Mass Flow (lb/hr)	25000.00	25000.00	-	-
<b>Component Mass Flow (lb/hr)</b>				
H <sub>2</sub> O	18093.3	18093.3	-	-
NH <sub>3</sub>	29.4	29.4	-	-
NH <sub>4</sub> <sup>+</sup>	0.6	0.6	-	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.9	29.9	-	-
H <sub>2</sub> S	0.000103	0.000103	-	-
HS-	0.1	0.1	-	-
S--	0.000039	0.000039	-	-
(H <sub>2</sub> S) + (HS-) + (S--)	0.1	0.1	-	-
C <sub>3</sub> H <sub>8</sub>	0.018	0.018	-	-
H <sub>3</sub> O <sup>+</sup>	0.00000014	0.00000014	-	-
OH-	0.3	0.3	-	-
N <sub>2</sub>	-	-	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> <sup>-</sup>	0.0	0.0	-	-
SO <sub>4</sub> <sup>--</sup>	0.6	0.6	-	-
<b>Design Data:</b>				
Heat duty (BTU/hr)	2,753,960			
MOC:	316 Stainless steel			
Type:	Fired Heater			
Operating Pressure (Psia)	55			
Orientation	HSC			
<b>Utilities:</b>	1992.7 lb/hr of natural gas			
<b>Comments and Drawings:</b>	See Section 15, Figure 15.1 PFD for Air Stripping Process			



<h2 style="margin: 0;">Air Heater</h2>				
<b>Identification:</b>	<b>Item</b> Item No. F-101 (air) No. required 1	<i>Air Fired Heater</i>	<b>Date:</b>	17-Apr-18
			<b>By:</b>	Team 5
<b>Function:</b>	Increase the temperature of the incoming air to the required temperature for the stripping process			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Feed( S8)</b>	<b>Discharge (S9)</b>	<b>N/A</b>	<b>N/A</b>
Temperature(°F)	70.0	158.00	-	-
Pressure(psia)	35.0	35.00	-	-
Pressure(psig)	20.3	20.30	-	-
Vapor Fraction	1.0	1.0	-	-
Molar Flow (lbmol/hr)	831.6	831.60	-	-
Volume Flow (cuft/hr)	134894.0	157436.00	-	-
Mass Flow (lb/hr)	23992.0	23992.00	-	-
Component Mass Flow (lb/hr)				
H <sub>2</sub> O	-	-	-	-
NH <sub>3</sub>	-	-	-	-
NH <sub>4</sub> <sup>+</sup>	-	-	-	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	-	-	-	-
H <sub>2</sub> S	-	-	-	-
HS-	-	-	-	-
S--	-	-	-	-
(H <sub>2</sub> S) + (HS-) + (S--)	-	-	-	-
C <sub>3</sub> H <sub>8</sub>	-	-	-	-
H <sub>3</sub> O <sup>+</sup>	-	-	-	-
OH-	-	-	-	-
N <sub>2</sub>	18404.1	18404.1	-	-
O <sub>2</sub>	5588.2	5588.2	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> -	-	-	-	-
SO <sub>4</sub> --	-	-	-	-
<b>Design Data:</b>				
Heat duty (BTU/hr)	542,901			
MOC:	Cr-Mo Alloy Steel			
Type:	Fired Heater			
Orientation	HSC			
Operating Pressure (Psia)	35			
<b>Utilities:</b>	412.24 lb/hr of natural gas, 1.61 Kwh of electricity			
<b>Comments and Drawings:</b>	See Section 15, Figure 15.1 PFD for Air Gas Stripping Process			

<b>Blower</b>				
<b>Identification:</b>	<b>Item</b> <i>Air Blower</i> <b>Item No.</b> B-100 <b>No. required</b> 1		<b>Date:</b> <i>17-Apr-18</i> <b>By:</b> <i>Team 5</i>	
<b>Function:</b>	Increase the pressure of the incoming air stream to the required pressure for the stripping process			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Feed( S7)</b>	<b>Discharge (S8)</b>	<b>N/A</b>	<b>N/A</b>
Temperature(°F)	70.0	70.0	-	-
Pressure(psia)	14.7	35.0	-	-
Pressure(psig)	0.0	20.3	-	-
Vapor Fraction	1.0	1.0	-	-
Molar Flow (lbmol/hr)	N/A	831.6	-	-
Volume Flow (cuft/hr)	N/A	134894.0	-	-
Mass Flow (lb/hr)	N/A	23992.0	-	-
<b>Component Mass Flow (lb/hr)</b>				
H <sub>2</sub> O	-	-	-	-
NH <sub>3</sub>	-	-	-	-
NH <sub>4</sub> <sup>+</sup>	-	-	-	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	-	-	-	-
H <sub>2</sub> S	-	-	-	-
HS <sup>-</sup>	-	-	-	-
S <sup>-2</sup>	-	-	-	-
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>-2</sup> )	-	-	-	-
C <sub>3</sub> H <sub>8</sub>	-	-	-	-
H <sub>3</sub> O <sup>+</sup>	-	-	-	-
OH <sup>-</sup>	-	-	-	-
N <sub>2</sub>	18404.1	-	-	-
O <sub>2</sub>	5588.2	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> <sup>-</sup>	-	-	-	-
SO <sub>4</sub> <sup>-2</sup>	-	-	-	-
<b>Design Data:</b>				
Shaft power	3600 rpm			
MOC	Aluminum			
Type:	Centrifugal Blower			
Orientation	HSC			
Flowrate (cuft/min)	4036			
Blower efficiency	0.75			
Motor efficiency	0.89			
<b>Utilities:</b>	23.32 KWh of electricity			
<b>Comments and Drawings:</b>	See Section 15, Figure 15.1 PFD for Air Stripping Process			

<h1>Stripping Column</h1>					
<b>Identification:</b>	<b>Item</b>	<i>Stripping Column (air)</i>		<b>Date:</b>	<i>17-Apr-18</i>
	Item No.	C-100		<b>By</b>	<i>Team 5</i>
	No. required	1			
<b>Function:</b>	Strip ammonia and hydrogen sulfide from sour water using air.				
<b>Operation:</b>	Continuous				
<b>Materials handled:</b>	<b>Air Feed (S12)</b>	<b>Sour Water Feed (S6)</b>	<b>Extract (S13)</b>	<b>Raffinate(S14)</b>	
Temperature(°F)	190.0	190.00	153.00	137.00	
Pressure(psia)	35.0	25.00	17.00	18.80	
Pressure(psig)	20.3	10.30	2.30	4.10	
Vapor Fraction	1.0	0.00	1.0	0.0	
Molar Flow (lbmol/hr)	924.0	1387.95	989.50	940.50	
Volume Flow (cuft/hr)	183841.0	37.5 (GPM)	382357	34.4	
Mass Flow (lb/hr)	25657.0	25000.00	26837.00	16944.20	
Component Mass Flow (lb/hr)					
H <sub>2</sub> O	1665.00	18093.3	2813	16943.0	
NH <sub>3</sub>	-	29.4	29.80	0.1	
NH <sub>4</sub> <sup>+</sup>	-	0.6	-	0.2	
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	-	29.9	29.8	0.3	
H <sub>2</sub> S	-	0.0	0.09	0.0	
HS <sup>-</sup>	-	0.1	0.0	0.0	
S <sup>--</sup>	-	0.0	0.0	0.0	
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>--</sup> )	-	0.1	0.0905	0.0	
C <sub>3</sub> H <sub>8</sub>	-	-	0.02	-	
H <sub>3</sub> O <sup>+</sup>	-	-	0.0	0.0	
OH <sup>-</sup>	-	0.3	0.0	0.0	
N <sub>2</sub>	18404.1	-	18403.9	0.2	
O <sub>2</sub>	5588.2	-	5588.1	0.1	
CH <sub>4</sub>	-	-	-	-	
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-	
HSO <sub>4</sub> <sup>-</sup>	-	-	-	0.0	
SO <sub>4</sub> <sup>--</sup>	-	0.6	-	0.6	
<b>Design Data:</b>					
Number of trays:	20		Tray spacing:	2 ft	
Pressure drop	3.11psi		skirt height	10ft	
Functional Height:	40 ft				
Material of Construction:	316 Stainless Steel				
Recommended inside diameter:	4.70094				
Tray efficiency:	0.25				
<b>Utilities:</b>	1665 lb/hr of steam @50psi				
<b>Comments and drawings:</b>	See Section 15, Figure 15.1 PFD for Air Stripping Process				

**Section 19.2: Specification Sheets for Natural Gas Stripping Process**

<b>Acid Storage Tank</b>				
<b>Identification:</b>	<b>Item</b>	<i>Acid Storage Tank (CH4)</i>		<b>Date:</b>
	Item No.	T-101 (CH4)		17-Apr-18
	No. required	1		By Team 5
<b>Function:</b>	Store sulfuric acid before use			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Discharge (S3)</b>	<b>N/A</b>	<b>N/A</b>	<b>N/A</b>
Temperature(°F)	80.0	-	-	-
Pressure(psia)	15.0	-	-	-
Operating Volume Flow (cuft/hr)	0.021	-	-	-
Molar vapor fraction	-	-	-	-
Molar Flow (lbmol/hr)	0.067	-	-	-
Mass Flow (lb/hr)	1.7	-	-	-
Component Mass Flow (lb/hr)				
H <sub>2</sub> O	1.00	-	-	-
NH <sub>3</sub>	-	-	-	-
NH <sub>4</sub> <sup>+</sup>	-	-	-	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	-	-	-	-
H <sub>2</sub> S	-	-	-	-
HS <sup>-</sup>	-	-	-	-
S <sup>--</sup>	-	-	-	-
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>--</sup> )	-	-	-	-
C <sub>3</sub> H <sub>8</sub>	-	-	-	-
H <sub>3</sub> O <sup>+</sup>	1.10E-01	-	-	-
OH <sup>-</sup>	-	-	-	-
N <sub>2</sub>	-	-	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> <sup>-</sup>	5.40E-01	-	-	-
SO <sub>4</sub> <sup>--</sup>	0.005	-	-	-
<b>Design Data:</b>				
Capacity	200 gal			
MOC:	Polyethylene			
Depth:	48"			
Diameter:	36" OD			
Wall	5/16"			
<b>Utilities:</b>	-			
<b>Comments and drawings:</b>	See Section 15, Figure 15.2 PFD for Natural Gas Stripping Process			

<b>Surge Tank</b>				
<b>Identification:</b>	<b>Item</b>	<i>Surge Tank (CH4)</i>		<b>Date:</b> 17-Apr-18
	Item No.	T-100 (CH4)		<b>By:</b> Team 5
	No. required	1		
<b>Function:</b>	Dampen any spikes in flow rate and ammonia concentration			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Sour Water from Refinery ( S1)</b>	<b>Recycle Stream (S15)</b>	<b>Discharge (S2)</b>	<b>N/A</b>
Temperature(°F)	80.0	140.00	80.00	-
Pressure(psia)	15.0	18.60	15.00	-
Operating Volume Flow (cuft/hr)	37.5 (GPM)	-	37.5 (GPM)	-
Molar vapor fraction	-	-	-	-
Molar Flow (lbmol/hr)	1006.0	-	1006.0	-
Mass Flow (lb/hr)	18122.4	-	18122.4	-
Component Mass Flow (lb/hr)				
H <sub>2</sub> O	18092.00	-	18093	-
NH <sub>3</sub>	29.48	-	29.36	-
NH <sub>4</sub> <sup>+</sup>	0.442	-	0.58	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.94	-	29.94	-
H <sub>2</sub> S	8.08E-05	-	8.08E-05	-
HS-	0.0878	-	0.0878	-
S--	4.86E-05	-	4.86E-05	-
(H <sub>2</sub> S) + (HS-) + (S--)	0.0879	-	0.0879	-
C <sub>3</sub> H <sub>8</sub>	0.018	-	0.018	-
H <sub>3</sub> O <sup>+</sup>	1.06E-07	-	1.06E-07	-
OH-	0.372	-	0.372	-
N <sub>2</sub>	-	--	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> <sup>-</sup>	-	-	-	-
SO <sub>4</sub> <sup>--</sup>	-	-	-	-
<b>Design Data:</b>				
Size	2500 gal			
MOC:	Fiberglass			
<b>Utilities:</b>	-			
<b>Comments and drawings:</b>	See Section 15, Figure 15.2 PFD for Natural Gas Stripping Process			

<b>Acid Mixing Tank</b>				
<b>Identification:</b>	<b>Item</b>	<i>Acid Mixing Tank (CH<sub>4</sub>)</i>		<b>Date:</b> 17-Apr-18
	Item No.	T-102 (CH <sub>4</sub> )		<b>By:</b> Team 5
	No. required	1		
<b>Function:</b>	Mix sulfuric acid with sour water to reduce the pH			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Sour Water Feed (S2)</b>	<b>Acid Feed (S3)</b>	<b>Discharge (S4)</b>	<b>N/A</b>
Temperature(°F)	80	80	80.00	-
Pressure(psia)	15	15	15.00	-
Operating Volume Flow (cuft/hr)	37.5	0.021	37.5	-
Molar vapor fraction	0.0	0.0	0	-
Molar Flow (lbmol/hr)	1006	0.067	1006.1	-
Mass Flow (lb/hr)	18122.4	1.65	18124	-
<b>Component Mass Flow (lb/hr)</b>				
H <sub>2</sub> O	18092	1.0	18093	-
NH <sub>3</sub>	29.48	-	29.37	-
NH <sub>4</sub> <sup>+</sup>	0.44	-	0.56	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.92	-	29.93	-
H <sub>2</sub> S	8.08E-05	-	1.01E-04	-
HS <sup>-</sup>	0.088	-	0.088	-
S <sup>--</sup>	4.86E-05	-	3.95E-05	-
(H <sub>2</sub> S) + (HS <sup>-</sup> ) + (S <sup>--</sup> )	0.088	-	0.09	-
C <sub>3</sub> H <sub>8</sub>	0.018	-	0.018	-
H <sub>3</sub> O <sup>+</sup>	1.06E-07	0.11	1.35E-07	-
OH <sup>-</sup>	0.37	-	0.30	-
N <sub>2</sub>	-	-	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	-	-	-	-
H <sub>2</sub> SO <sub>4</sub>	-	1.80E-09	-	-
HSO <sub>4</sub> <sup>-</sup>	-	0.54	1.34E-07	-
SO <sub>4</sub> <sup>--</sup>	-	0.005	0.54	-
<b>Design Data:</b>				
Capacity	400 gal			
MOC:	Stainless Steel			
Depth:	46-1/2"			
Diameter:	52" ID			
<b>Utilities:-</b>				
<b>Comments and drawings:</b>	See Section 15, Figure 15.2 PFD for Natural Gas Stripping Process			

<b>Sour Water Pump</b>					
<b>Identification:</b>	Item	<i>Sour Water Pump (CH<sub>4</sub>)</i>		Date:	<i>17-Apr-18</i>
	Item No.	P-100 (CH <sub>4</sub> )		By	<i>Team 5</i>
	No. required	1			
<b>Function:</b>	Strip ammonia and hydrogen sulfide from sour water using methane				
<b>Operation:</b>	Continuous				
<b>Materials handled:</b>	<b>Feed (S4)</b>	<b>Discharge (S5)</b>	<b>N/A</b>	<b>N/A</b>	
Temperature(°F)	80	80	-	-	
Pressure(psia)	15	55	-	-	
Operating Volume Flow (cuft/hr)	37.5	37.5	-	-	
Molar vapor fraction	0.0	0.0	-	-	
Molar Flow (lbmol/hr)	1006.1	1006.1	-	-	
Mass Flow (lb/hr)	18124.00	18124.00	-	-	
Component Mass Flow (lb/hr)					
H <sub>2</sub> O	18093	18,093.3	-	-	
NH <sub>3</sub>	29.37	29.37	-	-	
NH <sub>4</sub> <sup>+</sup>	0.56	0.56	-	-	
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.93	29.93	-	-	
H <sub>2</sub> S	1.01E-04	1.01E-04	-	-	
HS-	0.088	0.088	-	-	
S--	3.95E-05	3.95E-05	-	-	
(H <sub>2</sub> S) + (HS-) + (S--)	0.088	0.088	-	-	
C <sub>2</sub> H <sub>6</sub>	0.018	0.018	-	-	
H <sub>2</sub> O+	1.35E-07	1.35E-07	-	-	
OH-	0.30	0.30	-	-	
N <sub>2</sub>	-	-	-	-	
O <sub>2</sub>	-	-	-	-	
CH <sub>4</sub>	-	-	-	-	
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-	
HSO <sub>4</sub> -	1.34E-07	1.34E-07	-	-	
SO <sub>4</sub> --	0.54	0.54	-	-	
<b>Design Data:</b>					
Net Work	2.16523 Hp	Head	2 ft		
MOC:	Stainless Steel	Max Motor hp:	75 Hp		
Type:	Centrifugal Pump				
Orientation:	HSC				
shaft rpm:	3600				
Max. Flow (GPM)	50				
Head (ft-lbf/lb)	92.7483				
Pump Efficiency used:	0.39				
<b>Utilities:</b>	1.61461 KWh of electricity				
<b>Comments and drawings:</b>	See Section 15, Figure 15.2 PFD for Natural Gas Stripping Process				

<b>Sour Water Heater</b>					
<b>Identification:</b>	Item	<i>Sour Water Heater (CH<sub>4</sub>)</i>		Date:	<i>17-Apr-18</i>
	Item No.	F-100 (CH <sub>4</sub> )		By	<i>Team 5</i>
	No. required	1			
<b>Function:</b>	Increase the temperature of the incoming sour water to the required temperature for stripping				
<b>Operation:</b>	Continuous				
<b>Materials handled:</b>	<b>Feed (S5)</b>	<b>Discharge (S6)</b>	<b>N/A</b>	<b>N/A</b>	
Temperature(°F)	80	190	-	-	
Pressure(psia)	55	55	-	-	
Operating Volume Flow (cuft/hr)	37.5	37.5	-	-	
Molar vapor fraction	0.0	0.0	-	-	
Molar Flow (lbmol/hr)	1006.1	1006.1	-	-	
Mass Flow (lb/hr)	18124.00	18124.00	-	-	
Component Mass Flow (lb/hr)					
H <sub>2</sub> O	18093	18,093.3	-	-	
NH <sub>3</sub>	29.37	29.37	-	-	
NH <sub>4</sub> <sup>+</sup>	0.56	0.56	-	-	
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	29.93	29.93	-	-	
H <sub>2</sub> S	1.01E-04	1.01E-04	-	-	
HS-	0.088	0.088	-	-	
S--	3.95E-05	3.95E-05	-	-	
(H <sub>2</sub> S) + (HS-) + (S--)	0.088	0.088	-	-	
C <sub>3</sub> H <sub>8</sub>	0.018	0.018	-	-	
H <sub>3</sub> O <sup>+</sup>	1.35E-07	1.35E-07	-	-	
OH-	0.30	0.30	-	-	
N <sub>2</sub>	-	-	-	-	
O <sub>2</sub>	-	-	-	-	
CH <sub>4</sub>	-	-	-	-	
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-	
HSO <sub>4</sub> -	1.34E-07	1.34E-07	-	-	
SO <sub>4</sub> --	0.54	0.54	-	-	
<b>Design Data:</b>					
Heat duty (BTU/hr)	2,753,960				
MOC:	316 Stainless Steel				
Operating Pressure (Psia)	51				
Orientation	HSC				
<b>Utilities:</b>	163 lb/hr of natural gas, 1.61kwh of electricity				
<b>Comments and drawings:</b>	See Section 15, Figure 15.2 PFD for Natural Gas Stripping Process				



<b>Natural Gas Heater</b>				
<b>Identification:</b>	<b>Item</b>	<i>Natural Gas Heater (CH<sub>4</sub>)</i>		<b>Date:</b> 17-Apr-18
	Item No.	F-101(CH <sub>4</sub> )		<b>By</b> Team 5
	No. required	1		
<b>Function:</b>	Increase the temperature of the incoming natural gas to the required temperature for stripping			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>Feed (S8)</b>	<b>Discharge (S9)</b>	<b>N/A</b>	<b>N/A</b>
Temperature(°F)	42	180	-	-
Pressure(psia)	35	35	-	-
Operating Volume Flow (cuft/hr)	139626	178623	-	-
Molar vapor fraction	1.0	1.0	-	-
Molar Flow (lbmol/hr)	912.8	912.8	-	-
Mass Flow (lb/hr)	14644.00	14644	-	-
Component Mass Flow (lb/hr)				
H <sub>2</sub> O	-	-	-	-
NH <sub>3</sub>	-	-	-	-
NH <sub>4</sub> <sup>+</sup>	-	-	-	-
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	-	-	-	-
H <sub>2</sub> S	-	-	-	-
HS-	-	-	-	-
S--	-	-	-	-
(H <sub>2</sub> S) + (HS-) + (S--)	-	-	-	-
C <sub>3</sub> H <sub>8</sub>	-	-	-	-
H <sub>2</sub> O+	-	-	-	-
OH-	-	-	-	-
N <sub>2</sub>	-	-	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	14644.00	14,644.00	-	-
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> -	-	-	-	-
SO <sub>4</sub> --	-	-	-	-
<b>Design Data:</b>				
Heat duty (BTU/hr)	1,522,641			
MOC:	Cr-Mo Alloy Steel			
Type:	Fired Heater			
Orientation	HSC			
Operating Pressure (Psia)	35			
<b>Utilities:</b>	88 lb/hr of natural gas, 1.61kwh of electricity			
<b>Comments and drawings:</b>	See Section 15, Figure 15.2 PFD for Natural Gas Stripping Process			

<b>Natural Gas Stripping Column</b>				
<b>Identification:</b>	<b>Item</b>	<i>Natural Gas Stripping Column (CH<sub>4</sub>)</i>		<b>Date:</b>
	Item No.	C-100 (CH <sub>4</sub> )		<i>17-Apr-18</i>
	No. required	1		<i>Team 5</i>
<b>Function:</b>	Strip ammonia and hydrogen sulfide from sour water using methane			
<b>Operation:</b>	Continuous			
<b>Materials handled:</b>	<b>NatGas Feed (S12)</b>	<b>Sour Water Feed (S16)</b>	<b>Extract (S13)</b>	<b>Raffinate (S14)</b>
Temperature(°F)	190	190	151.5	140.00
Pressure(psia)	35	25	17	18.60
Operating Volume Flow (cuft/hr)	201,370	37.5 (GPM)	416,849	34.3 (GPM)
Molar vapor fraction	1.0	0	1.0	0.0
Molar Flow (lbmol/hr)	1014.2	1006.1	1,083.1	937.20
Mass Flow (lb/hr)	16471.0	18124.2	17,711.9	16,883.1
<b>Component Mass Flow (lb/hr)</b>				
H <sub>2</sub> O	1827.0	18,093.3	3037.0	16882.8
NH <sub>3</sub>	-	29.37	29.6	0.12
NH <sub>4</sub> <sup>+</sup>	-	0.56	-	0.21
(NH <sub>3</sub> ) + (NH <sub>4</sub> <sup>+</sup> )	-	29.93	29.6	0.327
H <sub>2</sub> S	-	1.01E-04	0.1	6.23E-06
HS-	-	0.088	-	2.26E-04
S--	-	3.95E-05	-	5.59E-10
(H <sub>2</sub> S) + (HS-) + (S--)	-	0.088	0.1	2.32E-04
C <sub>3</sub> H <sub>8</sub>	-	0.018	0.018	-
H <sub>2</sub> O <sup>+</sup>	-	1.35E-07	-	2.03E-06
OH-	-	0.30	-	0.0035
N <sub>2</sub>	-	-	-	-
O <sub>2</sub>	-	-	-	-
CH <sub>4</sub>	14644.0	-	14643.7	0.28
H <sub>2</sub> SO <sub>4</sub>	-	-	-	-
HSO <sub>4</sub> -	-	1.34E-07	-	7.95E-07
SO <sub>4</sub> --	-	0.54	-	0.55
<b>Design Data:</b>				
Number of trays:	17		Tray spacing:	2 ft
Pressure Drop:	2.42 psi		skirt height:	10ft
Functional Height:	34 ft			
Material of Construction:	316 Stainless Steel			
Recommended inside diameter:	4.58 ft			
Tray efficiency:	0.25			
<b>Utilities:</b>	1665 lb/hr of steam@ 50psi			
<b>Comments and drawings:</b>	See Section 15, Figure 15.2 PFD for Natural Gas Stripping Process			

Section 20  
**Equipment Cost Summary**

**Table 20.1.** Equipment Cost Summary for Air Stripping Process

	<b>Process Equipment ID</b>	<b>Type</b>	<b>Purchase Cost(\$)</b>	<b>Bare Module Factor</b>	<b>Bare Module Cost (\$)</b>
Surge Tank	T-100	Fabricated Equipment	\$17,407.00	3.21	\$55,876.47
Acid Storage Tank	T-101	Fabricated Equipment	\$616.00	3.21	\$1,977.36
Acid Mixing Tank	T-102	Fabricated Equipment	\$9,220.25	3.21	\$29,597.00
Sour Water Pump	P-100	Process Machinery	\$9,296.67	3.3	\$30,679.00
Sour Water Heater	F-100	Process Machinery	\$172,979.00	2.19	\$378,824.00
Air Blower	B-100	Process Machinery	\$75,387.44	2.15	\$162,083.00
Air Heater	F-101	Process Machinery	\$39,816.89	2.19	\$87,199.00
Stripping Column	C-100	Fabricated Equipment	\$177,417.31	4.16	\$738,056.00
<b>Total</b>			<b>\$502,140.56</b>		<b>\$1,484,291.83</b>

**Table 20.2.** Equipment Cost Summary for Natural Gas Stripping Process

	<b>Process Equipment ID</b>	<b>Type</b>	<b>Purchase Cost(\$)</b>	<b>Bare Module Factor</b>	<b>Bare Module Cost (\$)</b>
Surge Tank	T-100	Fabricated Equipment	\$17,407.00	3.21	\$55,876.47
Acid Storage Tank	T-101	Fabricated Equipment	\$616.00	3.21	\$1,977.36
Acid Mixing Tank	T-102	Fabricated Equipment	\$9,220.25	3.21	\$29,597.00
Sour Water Pump	P-100	Process Machinery	\$9,296.67	3.3	\$30,679.00
Sour Water Heater	F-100	Process Machinery	\$172,979.00	2.19	\$378,824.00
CH4 heater	F-101	Process Machinery	\$89,464.38	2.19	\$195,927.00
Stripping Column	C-100	Fabricated Equipment	\$163,651.92	4.16	\$680,792.00
<b>Total</b>			<b>\$462,635.22</b>		<b>\$1,373,672.83</b>

For all of the purchase and bare module cost calculations, a Chemical Engineering (CE) Index of 600 was used. This was done by assuming a 4% per year escalation from the December 2017 CE Index of 572.8 to project start-up in mid-2019.

In order to implement this project, a total permanent investment of \$1.78 MM is needed for the air stripping process. \$0.55 MM of the total permanent investment is spent on start-up of the project, contingencies and contractor fees, site preparations, and service facilities. The remaining \$1.23 MM is spent on buying the process equipment and installation fees as is shown in Table 20.1 above. On the other hand, a total permanent investment of \$1.64 MM is needed for the natural gas stripping process. \$0.53 MM of this total permanent investment is also spent on start-up of the project, contingencies and contractor fees, site preparations, and service facilities. The remaining \$1.11 MM is spent on buying the process equipment and installation fees as seen in Table 20.2 above.

**Table 20.3.** Breakdown of Total Equipment Costs for the Air Stripping Process. The stripping column is the most expensive equipment followed by the sour water heater. The sour water pump and tanks are the least expensive ones.

<b>Equipment</b>	<b>Percentage of Total Purchase Cost</b>
Surge Tank	3.76%
Acid Storage Tank	0.13%
Acid Mixing Tank	1.99%
Sour Water Pump	2.07%
Sour Water Heater	25.52%
Air Heater	10.92%
Blower	5.87%
Stripping Column	49.72%

Of the \$1.48 MM required for all pieces of equipment for the air stripping process, the stripping column is the most expensive equipment, comprising of 49.72% of the total cost followed by the sour water heater and air heater at \$0.38 MM (25.52%) and \$0.16 MM (10.92%), respectively. The acid storage tank and acid mixing tank are the least expensive due to their small sizes.

**Table 20.4.** Breakdown of Total Equipment Costs for the Natural Gas Stripping Process. The sour water pump is the most expensive equipment followed by the stripping column. The sour water pump and tanks are the least expensive ones.

<b>Equipment</b>	<b>Percentage of Total Purchase Cost</b>
Surge Tank	4.07%
Acid Storage Tank	0.14%
Acid Mixing Tank	2.15%
Sour Water Pump	2.23%
Sour Water Heater	27.58%
CH4 heater	14.26%
Stripping Column	49.56%

Of the \$1.37 MM required for all pieces of equipment for the air stripping process, the stripping column is the most expensive equipment, comprising of 49.56% of the total cost followed by the sour water heater and natural gas heater at \$0.38MM (27.58%) and \$0.20 MM (14.26%), respectively. The acid storage tank and acid mixing tank are the least expensive due to their small sizes.

All in all, the total equipment cost for the air stripping process is higher than that for the natural gas stripping process; the air stripping process requires an air blower unlike the natural gas stripping process, and comprises of 10.92% of the total equipment cost.

## Section 20.1: Unit Costing Considerations

For the air stripping process, optimizations of the stripping column, air heater, and air blower were done simultaneously. This is so because the variation of the number of stages affects the amount of air required for stripping. For instance, reducing the number of stages to get a column of reasonable height and price for successful stripping would require more air for stripping. The increase in the amount of air required for stripping increased the price for the air blower and air heater as they are highly dependent on the amount of air.

For the natural gas stripping, only the stripping column and natural gas heater were done simultaneously because the process had a depressurizing valve instead of a blower.

### Section 20.1.1: Air and Natural Gas Stripping Column

The air and natural gas stripping column were costed based on their diameters, tray types, height, and material of construction. This was in accordance with equations provided in Chapter 16 of *Product and Process Design Principles*<sup>25</sup> for a vertical pressure vessel with trays, and the costing spreadsheet provided with the required equations. Stainless steel was chosen as the material of construction in order to avoid corrosion in the stripping column as said in Section 18. The inputs used in these equations were retrieved from the ASPEN process simulation results. The input values used can be found in the specification spreadsheets in Section 19.

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<sup>25</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

### Section 20.1.2: Sour Water and Air/ Natural Gas Heaters

Sour water and air/natural gas heaters were costed based on the material of construction, flowrate of the sour water, air, and natural gas and the amount of heat required to achieve the heating. The equations used in these calculations can be found in Chapter 16 of Product and Process Design Principles.<sup>26</sup> The inputs for these calculations are from the ASPEN process simulation stream results presented in Section 15.

### Section 20.1.3: Air Blower

The centrifugal air blower was costed based on its volumetric flow rate it delivers and the inlet and outlet pressures as seen in Section 18. Its purchase and bare module costs were determined using equations 16.30 and 16.32 in Chapter 16 of Product and Process Design Principles<sup>27</sup>.

### Section 20.1.4: Sour Water Pump

The centrifugal pump's costing equations in Chapter 16 of Product and Process Design Principles<sup>28</sup> were used in order to design and determine the purchase and bare module cost. The pump head and the flowrate through the pump were crucial in these calculations and they are presented in Section 18. The other factors taken into consideration, like the rate of rotation and material of construction, can be found in the specification sheets in Section 19.

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<sup>26</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

<sup>27</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

<sup>28</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.



**Section 20.1.5: Acid Storage Tank, Acid Mixing Tank, and Surge Tank.**

The acid storage tank, T-101 and acid mixing tank, T-102, were each costed based on purchase prices from INDCO, whose quotes can be found in the Appendix (A.4.2 and A.4.3), and on the assumed volume of storage and mixing as described in Section 18.1.2 and Section 18.1.3. The surge tank, T-100, was costed based on the surge tank pricing equation from Chapter 16 of *Product and Process Design Principles*,<sup>29</sup> and on the assumed volume required as described in Section 18.1.1.

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<sup>29</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

Section 21

# **Fixed-Capital Investment Summary**

In order to calculate the purchase cost of each major equipment, the Equipment Cost Spreadsheet<sup>30</sup> was used to calculate the bare module cost. The purchase cost was then calculated based on the obtained bare module cost and the bare module factor. These costs can be seen in Table 20.1 and Table 20.2 for the air stripping process and the natural gas stripping process. To calculate the total capital investment, its components presented in Table 16.9 of Chapter 16 of Product and Process Design Principles<sup>31</sup> were first calculated. These components are shown in Figure 21.1 below.

**Table 21.1.** Different Costs needed to calculate the Total Capital Investment<sup>32</sup>

Total bare-module costs for fabricated equipment	$C_{FE}$			
Total bare-module costs for process machinery	$C_{PM}$			
Total bare-module costs for spares	$C_{spare}$			
Total bare-module costs for storage and surge tanks	$C_{storage}$			
Total cost for initial catalyst charges	$C_{catalyst}$			
Total bare-module costs for computers and software, including distributed control systems, instruments, and alarms	$C_{comp}$			
Total bare-module investment, TBM		$C_{TBM}$		
Cost of site preparation		$C_{site}$		
Cost of service facilities		$C_{serv}$		
Allocated costs for utility plants and related facilities		$C_{alloc}$		
Total of direct permanent investment, DPI			$C_{DPI}$	
Cost of contingencies and contractor's fee			$C_{cont}$	
Total depreciable capital, TDC				$C_{TDC}$
Cost of land				$C_{land}$
Cost of royalties				$C_{royal}$
Cost of plant startup				$C_{startup}$
Total permanent investment, TPI				$C_{TPI}$
Working capital				$C_{wc}$
Total capital investment, TCI				$C_{TCI}$

<sup>30</sup> Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).

<sup>31</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

<sup>32</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

The corresponding calculations for each of the costs mentioned in Table 21.1 are shown in Table 21.2 and Table 21.3 for sour water stripping using air and sour water stripping using natural gas, respectively.

**Table 21.2** Total capital investment calculations for sour water stripping with air from equipment bare module costs<sup>33</sup>

<b>Investment Summary</b>		
<b><u>Total Bare Module Costs:</u></b>		
Fabricated Equipment	\$	562,557
Process Machinery	\$	658,785
Spares	\$	-
Storage	\$	-
Other Equipment	\$	-
Catalysts	\$	-
Computers, Software, Etc.	\$	-
<b><u>Total Bare Module Costs:</u></b>	<b>\$</b>	<b><u>1,221,342</u></b>
<b><u>Direct Permanent Investment</u></b>		
Cost of Site Preparations:	\$	61,067
Cost of Service Facilities:	\$	61,067
Allocated Costs for utility plants and related facilities	\$	-
<b><u>Direct Permanent Investment</u></b>	<b>\$</b>	<b><u>1,343,476</u></b>
<b><u>Total Depreciable Capital</u></b>		
Cost of Contingencies & Contractor Fees	\$	241,826
<b><u>Total Depreciable Capital</u></b>	<b>\$</b>	<b><u>1,585,302</u></b>
<b><u>Total Permanent Investment</u></b>		
Cost of Land:	\$	31,706
Cost of Royalties:	\$	-
Cost of Plant Start-Up:	\$	158,530
<b>Total Permanent Investment - Unadjusted</b>	<b>\$</b>	<b>1,775,538</b>
Site Factor		1.00
<b><u>Total Permanent Investment</u></b>	<b>\$</b>	<b><u>1,775,538</u></b>

<sup>33</sup> Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).

**Table 21.3** Total capital investment calculations for sour water stripping with natural gas from equipment bare module costs<sup>34</sup>

<b>Investment Summary</b>		
<b><u>Total Bare Module Costs:</u></b>		
Fabricated Equipment	\$	525,172
Process Machinery	\$	605,430
Spares	\$	-
Storage	\$	-
Other Equipment	\$	-
Catalysts	\$	-
Computers, Software, Etc.	\$	-
<b><u>Total Bare Module Costs:</u></b>	<b>\$</b>	<b><u>1,130,602</u></b>
<b><u>Direct Permanent Investment</u></b>		
Cost of Site Preparations:	\$	56,530
Cost of Service Facilities:	\$	56,530
Allocated Costs for utility plants and related facilities	\$	-
<b><u>Direct Permanent Investment</u></b>	<b>\$</b>	<b><u>1,243,662</u></b>
<b><u>Total Depreciable Capital</u></b>		
Cost of Contingencies & Contractor Fees	\$	223,859
<b><u>Total Depreciable Capital</u></b>	<b>\$</b>	<b><u>1,467,521</u></b>
<b><u>Total Permanent Investment</u></b>		
Cost of Land:	\$	29,350
Cost of Royalties:	\$	-
Cost of Plant Start-Up:	\$	146,752
<b>Total Permanent Investment - Unadjusted</b>	<b>\$</b>	<b>1,643,624</b>
Site Factor		1.00
<b><u>Total Permanent Investment</u></b>	<b>\$</b>	<b><u>1,643,624</u></b>

From Table 21.2 and Table 21.3 above, it can be seen that stripping with natural gas requires a total permanent investment of \$131,914 less than stripping with air.

<sup>34</sup> Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).

Section 22

# Operating Cost – Cost of Manufacture

**Section 22.1: Variables Costs**

Since the goal of our project is to strip ammonia and hydrogen sulfide and trace amount of propane from sour water, we are not producing any product to be sold. We had contemplated separating the ammonia from the extract gas phase and selling it, but the economics were not favorable. For example, we would produce 120 tons of ammonia/year sold at \$500/ton, which corresponds to only \$60,000/year (Appendix: A.1.4). This yearly revenue was determined to not be enough per year to sell as the equipment required to remove it from the air stream would cost more to buy, install, and operate than we would make selling it for the foreseeable future. Since we are not selling any product, all variable operating costs were calculated based on the average amount of sweet water produced in each case: stripping with air or stripping with natural gas. For stripping with air, the basis for our raw materials and utilities calculations was 16,944.2 lb/hr of sweet water. For stripping with natural gas, the basis was 16,883.1 lb/hr of sweet water.

In order to start operations, the project would have to pay a total of \$7,475 for wastewater and air quality permits as well as permit applications and operating fees as mentioned in Section 23.1.

### Section 22.1.1: Raw Materials

**Table 22.1.** Raw Materials Cost and Yearly Requirements for Sour Water Stripping Using Air

Raw Material	Cost(\$/lb)	Yearly Requirement(lb)	Total Annual Cost (\$/yr)
Air	--	192 MM	--
Sour Water	--	145 MM	--
Sulfuric Acid	\$0.14	0.0144 MM	(0.002 MM)
<i>Total</i>	-		<i>(0.002 MM)</i>

**Table 22.2.** Raw Materials Cost and Yearly Requirements for Sour Water Stripping Using Natural Gas (CH<sub>4</sub>)

Raw Material	Cost(\$/lb)	Yearly Requirement(lb)	Total Annual Cost (\$/yr)
CH <sub>4</sub>	\$0.06	117 MM	(7.03 MM)
Sour Water	--	145 MM	--
Sulfuric Acid	\$0.14	0.0132 MM	(0.002 MM)
<i>Total</i>	-		<i>(7.03 MM)</i>

For both air and natural gas stripping, sour water used in the process comes directly from within the refinery at no cost. For air stripping, air used in the stripping process is free. For natural gas stripping however, the natural gas is bought and sold to and from the refinery for \$5.00/1,000 SCF<sup>35</sup>. Due to Henry's law, 0.0019%, or 2,225 of the 117.1 MM pounds, of methane ends up in the raffinate water. As a result, we will only sell back 99.9981% of the methane used to strip to the refinery. Additionally, the process needs 1.8 lb/hr of sulfuric acid solution for air stripping compared to 1.65 lb/hr for natural gas stripping, which is bought at \$0.1375/lb.

<sup>35</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.



### Section 22.1.2: Utilities

**Table 22.3** Utility Cost and Yearly Requirements for Sour Water Stripping Using Air

Utilities	Cost(\$)	Required Ratio (per lb of sweet water)	Cost(\$/hr)	Total cost (\$/yr)
Steam @50psi	0.006/lb	0.098	\$9.96	(0.08 MM)
natural gas	0.061/lb	0.025	\$25.84	(0.207 MM)
electricity	0.070/Kwh	0.00147	\$1.74	(0.014 MM)
<i>Total</i>	-	-	-	<i>(0.301MM)</i>

**Table 22.4** Utility Cost and Yearly Requirements for Sour Water Stripping Using Natural Gas (CH<sub>4</sub>)

Utilities	Cost(\$)	Required Ratio (per lb of sweet water)	Cost(\$/hr)	Total cost (\$/yr)
Steam @50psi	0.006/lb	0.099	\$10.03	(0.08 MM)
natural gas	0.061/lb	0.015	\$15.45	(0.12 MM)
electricity	0.070/Kwh	9.56E-05	\$0.11	(0.0009MM)
<i>Total</i>	-	-	-	<i>(0.201MM)</i>

Natural gas used in fired heaters to heat sour water, air, and natural gas in different scenarios before entering the stripper is purchased from the refinery at \$5.00/1,000 SCF<sup>36</sup>. 427.9 lb/hr of natural gas is needed for fired heaters in sour water stripping with air whereas 251 lb/hr of natural gas is needed for fired heaters in sour water stripping with natural gas.

The sum of variable costs from Table 22.1-22.4 is \$0.301 MM for the air stripping process. The total of \$7.231 MM for the natural gas stripping process doesn't include the natural gas sent back to the refinery. This natural gas sent back totals \$7.12 MM per year and this reduces the annual variable costs for the natural gas stripping process to \$0.201 MM per year. The \$0.09 MM difference in these annual variable costs is mainly due to a difference in the utility costs of these two processes. This is mainly because for the air stripping process, more electricity is needed for the blower in the air stripping, which is not present in the natural gas stripping process. The

<sup>36</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

function of this air blower can be seen in Section 18.2.1 and the electricity requirement calculation was based on equations in Chapter 16 of Product and Process Design Principles<sup>37</sup>.

### Section 22.2: Fixed Costs

**Table 22.5.** Labor-related Operation Expenses for Sour Water Stripping with Air and Natural Gas (CH4)

Labor-related Operations	Cost	Total Annual Cost(\$/yr) (AIR)	Total Annual Cost(\$/yr) (CH4)
Direct Wages and Benefits	\$40/operator hour	0.998 MM)	(0.998 MM)
Direct Salaries and Benefits	15% of direct wages and benefits	(0.150 MM)	(0.150 MM)
Operating Supplies and Services	6% of direct wages and benefits	(0.060 MM)	(0.060 MM)
Technical Assistance to Manufacturing	\$60,000/yr/operator/shift	(0.720MM)	(0.720MM)
Control Laboratory	\$65,000/yr/operator/shift	(0.780 MM)	(0.780 MM)
<b>Total Operations</b>	-	<b>(2.708 MM)</b>	<b>(2.708 MM)</b>

For this process, we assumed there will be three eight-hour shifts and that we will have 2 operators and 2 engineers per shift. One operator will be in the control room another in the field to make sure everything is going well and to assist the control room operator just in case something needs to be adjusted. The field operator will also be in charge of loading raw materials. All the remaining data used were taken from Chapter 17 of Product and Process Design Principles<sup>38</sup>.

**Table 22.6.** Maintenance Expenses for Sour Water Stripping with Air and Natural Gas (CH4)

Maintenance	Cost	Total Annual Cost(\$/yr) (AIR)	Total Annual Cost(\$/yr) (CH4)
Wages and Benefits	4.5% Total Depreciable Capital	(0.071 MM)	(0.066 MM)
Salaries and Benefits	25% Maintenance Wages and Benefits	(0.018 MM)	(0.017 MM)
Materials and Services	100% Maintenance Wages and Benefits	(0.071 MM)	(0.066 MM)
Maintenance Overhead	5% Maintenance Wages and Benefits	(0.004 MM)	(0.003 MM)
<b>Total Maintenance</b>		<b>(0.164 MM)</b>	<b>(0.152 MM)</b>

<sup>37</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

<sup>38</sup> Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.

**Table 22.7.** General Expenses for Sour Water Stripping with Air and Natural Gas (CH4)

General Expenses	Cost	Total Annual Cost(\$/yr) (AIR)	Total Annual Cost(\$/yr) (CH4)
General Plant Overhead	7.1% Maintenance Operations Wages and Benefits	(0.088 MM)	(0.087 MM)
Mechanical Department Services	2.4% Maintenance Operations Wages and Benefits	(0.030 MM)	(0.030 MM)
Employee Relations Department	5.9% Maintenance Operations Wages and Benefits	(0.073 MM)	(0.073 MM)
Business Services	7.4% Maintenance Operations Wages and Benefits	(0.092 MM)	(0.091 MM)
Property Tax and Insurance	2% Total Depreciable Capital	(0.032 MM)	(0.029 MM)
<i>Total</i>		<i>(0.315 MM)</i>	<i>(0.310MM)</i>

The sum of fixed expenses in Tables 22.5-22.7 gives \$3.19 MM in annual fixed costs for the air stripping process and \$3.17 MM for natural gas. They are almost similar because the general expenses, maintenance, and labor-related operations will be similar.

Section 23

# **Other Important Considerations**

### Section 23.1: Environmental Review

Environmental considerations for this project are of paramount importance. The harmfulness of the contaminants in water to humans, marine life, and the atmosphere is the reason for the sour water stripping technology. In fact, the design of the process and stripper are driven by the environmental regulations. Federal agencies such as the Environmental Protection Agency (EPA) and state agencies like the Department of Environmental Protection (DEP) issue regulations to plants and refineries that limit the amount harmful, toxic, or cancerous pollutants that can be released into the environment. The EPA identifies harmful pollutants but lacks the budget and bandwidth to monitor the emissions of all facilities.<sup>39</sup> Therefore, the EPA requires state agencies to enforce the national emission limits through a State Implementation Plan (SIP) submitted to the EPA for approval.<sup>40</sup> The state agencies also have the authority to create additional emission restrictions so long as they meet minimum restrictions imposed by the EPA. These regulations are made clear in an operating permit issued by the state regulatory agency.<sup>41</sup> The penalties associated with noncompliance and permit violations can be severe, and include fines, imprisonment, and even plant termination.<sup>42</sup> <sup>43</sup> There are two major environmental criteria to satisfy in order to consider the project successful: achieving acceptable emissions in the water and atmosphere.

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<sup>39</sup> Frederick, Andrew E, and Edward Wiener. "Emission Limits of Ammonia in Philadelphia." 16 Apr. 2018. Edward is an Environmental Engineer for Philadelphia Air Management Services.

<sup>40</sup> South, Mia. "Approved Air Quality Implementation Plans." *EPA*, Environmental Protection Agency, 29 Sept. 2017, [www.epa.gov/air-quality-implementation-plans/approved-air-quality-implementation-plans](http://www.epa.gov/air-quality-implementation-plans/approved-air-quality-implementation-plans).

<sup>41</sup> Frederick, Andrew E, and Robert Schlosser. "Emission Limit for Ammonia." 12 Apr. 2018. Robert is a Principal Project Manager at IES Engineers

<sup>42</sup> "CWA Section 404 Enforcement Overview." *EPA*, Environmental Protection Agency, 17 Nov. 2017, [www.epa.gov/cwa-404/cwa-section-404-enforcement-overview](http://www.epa.gov/cwa-404/cwa-section-404-enforcement-overview).

<sup>43</sup> "Penalties Associated with Violating U.S. Environmental Laws." *EnviroGuide*, Mar. 2013, [enviroguides.us/content/%E2%80%93penalties-associated-violating-us-environmental-laws](http://enviroguides.us/content/%E2%80%93penalties-associated-violating-us-environmental-laws).

To begin the environmental analysis, the toxicity of the pollutants dissolved in water will be investigated first. The two pollutants that could harm the environment and require in-depth analysis in this project are ammonia and hydrogen sulfide.

The primary objective behind the project is to convert the large amounts of ammonia (300-3,000 ppm) dissolved in water to the gaseous phase. When dissolved in water, ammonia mostly becomes its ionized form of ammonium. Ammonium is acutely and chronically toxic to fish and other marine organisms. Furthermore, it can easily be oxidized to nitrite which is also dangerous to marine life. It has been shown that the lethal concentration of ammonia in water ranges from 0.2 to 2.0 ppm<sup>44</sup> for various fish species. Ammonium is dangerous to humans as well but only for long term consumption at moderate levels. Although the EPA has not established a maximum contaminant level of ammonia in drinking water, the National Science of Academy recommends a standard in drinking water of 0.5 ppm because long term ingestion of water at 1 ppm can cause adverse health effects.<sup>45</sup> Hydrogen sulfide is also harmful to the environment as a gas dissolved in water. It is extremely toxic to life, even in small concentrations.<sup>46</sup> Additionally, it is highly corrosive and can damage steel on boats or docks in the water.<sup>47</sup>

Because of the damaging effects of ammonia and hydrogen sulfide in water, state and federal agencies have issued specific emission limits for pollutants in water. The Clean Water Act (CWA), administered by the EPA, is the primary federal law in the United States governing water pollution. It was first enacted in 1948 and completely rewritten in 1972. The CWA provides guidelines for state agencies to create permits to regulate industrial and municipal emissions. One

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<sup>44</sup> Oram, Brian. "Ammonia in Groundwater, Runoff, and Streams." *Water Research Center*, June 2014, [www.water-research.net/index.php/ammonia-in-groundwater-runoff-and-streams](http://www.water-research.net/index.php/ammonia-in-groundwater-runoff-and-streams).

<sup>45</sup> *Health Effects Information: Ammonia*. Public Health Office, 2000, *Health Effects Information: Ammonia*.

<sup>46</sup> QMax Solutions. "Overview of H<sub>2</sub>S." *Tech Bulletin #13*.

<sup>47</sup> Vaquer-Sunyer, Raquel. "Ecosystem Impacts of Hypoxia: Thresholds of Hypoxia and Pathways to Recovery." *Research Gate*, 2011.

important divergence within the CWA that will determine a refinery's guidelines is the distinguishment between a point and a non-point source.<sup>48</sup> According to the CWA, a point source is defined to be "any discernible, confined, and discrete conveyance from which pollutants are or may be discharged".<sup>49</sup> Oil refineries and other industrial facilities are thus classified as point sources. Point sources must adhere to and obtain a permit from the National Pollutant Discharge Elimination System (NPDES) before discharging pollutants to surface waters. The NPDES permit mandates that states investigate two areas to control emissions: technology based limitations and water quality based limitations. Technology based limitations refer to the technological and economic ability of dischargers in the same category to control the discharge of pollutants and water quality based limitations refer to the current state of pollution of the body of water receiving the discharge.<sup>50</sup>

Because different bodies of water contain various pollutants with a wide range of concentrations, states are authorized to create their own limits to which industrial facilities must adhere. For the purposes of this project, we will assume that the plant will be near Philadelphia and have access to the Delaware River. Because the Delaware River was bustling with factories and refineries after the Industrial Revolution, it was subject to a lot of polluted abuse. In fact, according to a newspaper article from 1940, the "rotten egg" smell of the water due to hydrogen sulfide was so strong that it threatened the usefulness of Philadelphia as a port.<sup>51</sup> For this reason, the Delaware River Basin Commission (DRBC) was founded in 1961 as an interstate compact

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<sup>48</sup> "Key Federal Laws: Clean Water Act." *Chem Alliance*, 2016, [www.chemalliance.org/tools/?subsec=25&id=6922](http://www.chemalliance.org/tools/?subsec=25&id=6922).

<sup>49</sup> "Clean Water Act, Section 502 General Definitions." *EPA*, Environmental Protection Agency, 15 Sept. 2016, [www.epa.gov/cwa-404/clean-water-act-section-502-general-definitions](http://www.epa.gov/cwa-404/clean-water-act-section-502-general-definitions).

<sup>50</sup> "Key Federal Laws: Clean Water Act." *Chem Alliance*, 2016, [www.chemalliance.org/tools/?subsec=25&id=6922](http://www.chemalliance.org/tools/?subsec=25&id=6922).

<sup>51</sup> "Usefulness of City as a Port Threatened by River Fumes." *The Philadelphia Record*, 14 Aug. 1944.

between New York, New Jersey, Pennsylvania, and Delaware to ensure fair treatment of the river by all parties. Based on the technology available to limit emissions into the water and the current state of the river, the DRBC has set the limit for the emission of ammonia dissolved in water at an average of 20 ppm over a 30 day period.<sup>52</sup> The DRBC has not set a limit on the amount of hydrogen sulfide that can be released into the Delaware River, but we will assume that it is negligible beyond the detectable limit, or <0.1 ppm.<sup>53</sup> These numbers are in line with the literature from a 1984 breakthrough report from Patricia Mackenzie listed in Table 24.1<sup>54</sup>, which also shows the effluent limits if the water stream were to be recycled and used elsewhere in the plant.

**Table 23.1:** Literature standards for Sour Water Stripping Effluent. King, et al., 1981.

SPECIES	CONCENTRATIONS OF DISSOLVED GASES (ppm)		
	FEED	EFFLUENT LIMITS	
		RELEASE	RECYCLE TO COOLING TOWER
AMMONIA	1000-30,000	1-15	5-100
SULFIDE	20-30,000	0.1-10	1-5
CARBONATE (as CaCO <sub>3</sub> )	1500-25,000	-	10-350
pH	7.5-9.5	6-8.5	7-8.5

Source: King et. al., 1981.

For the purpose of this project we will solely be analyzing the option of releasing the water into the river rather than recycling it to the cooling tower as we do not have enough information regarding quantity of water needed for the cooling tower and composition

<sup>52</sup> "18 CFR Part 410." *Delaware River Basin Commission*, 4 Dec. 2013, p. 111.

<sup>53</sup> Wanek, Rick. "Monitoring H<sub>2</sub>S to Meet New Exposure Standards." *Occupational Health & Safety*, 1 Sept. 2011, [ohsonline.com/articles/2011/09/01/monitoring-h2s-to-meet-new-exposure-standards.aspx](http://ohsonline.com/articles/2011/09/01/monitoring-h2s-to-meet-new-exposure-standards.aspx).

<sup>54</sup> Mackenzie, Patricia Denise, and C. J. King. "Simultaneous stripping and solvent extraction for the recovery of ammonia and acid gases from wastewaters." (1984).



requirements. Additionally, recycling sweeter water to the cooling tower is traditionally done in arid climates with low-volume waterways and expensive water utilities. Having analyzed the tight emission limits for ammonia and hydrogen sulfide in water, we will now look at the emission Gaseous ammonia's most popular application is in the agriculture industry. In fact, over 90%<sup>55</sup> of all ammonia in the atmosphere comes from ammonium nitrate, which is used as a fertilizer and ammonia is produced in large amounts from cow excrement. By itself, ammonia is not very dangerous. There are few, if any, reports of death via exposure to high amounts of ammonia<sup>56</sup>. However, people are susceptible to irritation at concentrations as low as 30 ppm. The Occupational Safety and Health Administration (OSHA) has set an 8 hour exposure limit to ammonia at 25 ppm and a 15 minute exposure limit to ammonia at 35 ppm (Appendix: A.6.1). These limits are for workers dealing with the chemical in close quarters and confined spaces. In the expansive atmosphere, ammonia is much less dangerous to humans and the environment.

Hydrogen sulfide on the other hand is extremely hazardous. It is a flammable gas that can irritate the lungs, eyes, and nose and cause nausea and confusion at low levels of 10 ppm (Appendix: A.6.1). Being exposed to hydrogen sulfide at high levels will result in unconsciousness and sometimes death. Hydrogen sulfide has a very strong "rotten-egg" scent at 0.1 ppm so it can be detected, but at higher concentrations the smell is undetectable and the gas can lead to instant death. OSHA has set the exposure limit to hydrogen sulfide at 1 ppm averaged over an 8 hour work shift.

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<sup>55</sup> Phillips, Jennifer. *Control and pollution prevention options for ammonia emissions*. No. PB-95-241790/XAB. VIGYAN, Inc., Vienna, VA (United States), 1995.

<sup>56</sup> "Ammonia Acute Exposure Guideline Levels." *Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 6.*, U.S. National Library of Medicine, 1 Jan. 1970, [www.ncbi.nlm.nih.gov/books/NBK207883](http://www.ncbi.nlm.nih.gov/books/NBK207883)

With respect to ammonia emission limits, the EPA has not imposed national regulations as to how much ammonia a refinery or plant can release.<sup>57</sup> While a lot of environmentalists called for the EPA to regulate ammonia under the Clean Air Act, the EPA resisted to include it because of the uncontrollable amount that is released from livestock.<sup>58</sup> Environmentalists urging for the regulation of ammonia is supported by the amount of ammonia refineries release into the atmosphere. In a report on all refineries across the U.S., ammonia was the highest emitted pollutant in units of pounds for every year from 2008-2012.<sup>59</sup> Roughly 5.5 million pounds of ammonia was released into the atmosphere by refineries between 2008 and 2012, more than any other pollutant.

Although ammonia is currently unregulated by federal agencies, there has been growing concern over its harmful potential to the environment. Studies have been conducted showing ammonia's role in forming particulate matter of 2.5 microns or less.<sup>60 61</sup> In 2007, the EPA deemed that states have the option to regulate precursors to particulate matter in non-attainment areas, or areas where the air quality is worse than the National Ambient Air Quality Standards (NAAQS).<sup>62</sup> As a result, state agencies have been stringent on imposing limits on the amount of ammonia refineries can release. An example of the state regulating refineries can be seen with the Marcus Hook refinery. Marcus Hook was a Sunoco operated refinery that produced 178,000 barrels of oil per day located 20 minutes outside of Philadelphia. From the excess amounts of ammonia that the refinery was producing, the Pennsylvania DEP implemented ammonia emission limits on the

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<sup>57</sup> Shaver, Sally. "The Regulation of Ammonia Emissions in the United States." U.S. EPA, 18 July 2008.

<sup>58</sup> Baise, Gary. "More EPA Regulation of Ammonia?" *Farm Futures*, 6 Oct. 2016, [www.farmfutures.com/blogs-more-epa-regulation-ammonia-9456](http://www.farmfutures.com/blogs-more-epa-regulation-ammonia-9456).

<sup>59</sup> McAngus, Jess. *Refinery Air Emission Metrics*. Spirit Environmental, LLC, 2013, *Refinery Air Emission Metrics*.

<sup>60</sup> "2014 National Emissions Inventory (NEI) Data." EPA, Environmental Protection Agency, 2 Mar. 2018, [www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data](http://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data).

<sup>61</sup> "Agricultural Air Pollution Fact Sheet." *Texas A&M Center for Agricultural Air Quality Engineering & Science*.

<sup>62</sup> Mathias, Scott. "Managing Air Quality: State Implementation Plans." U.S. EPA, 3 Oct. 2007.

refinery. These limits were strict. The refinery could not release more than 8.5 pounds per hour of ammonia averaged monthly and could not release more than 37.3 tons over any 12 month period. These numbers are significantly less than the 122 tons/year and 29.6 lb/hr of ammonia that the design with air as a stripping agent is estimated to release. This permit was issued in 2008 but the refinery was shut down in 2011 for deteriorating market conditions (Appendix: A.3.2). While the DEP was quick to regulate ammonia emissions in some refineries, it did not do so in others. For the United Refining plant in Warren, PA, the DEP made no effort to regulate ammonia emissions. The permit was issued in 2012 and contains no ammonia regulations (Appendix: A.3.1). The reason for ammonia regulations for some refineries can most likely be attributed to their location. The Marcus Hook refinery is located in Delaware County, which is one of 5 non-attainment areas for particulate matter in Pennsylvania. The Warren refinery is in Warren County and is an attainment area, or an area where the surrounding air is better than the NAAQS standards (Appendix: A.3.1). Philadelphia is an attainment area, so the DEP does not have the authority to regulate ammonia emissions. However, it is located adjacent to Delaware County, so a deterioration in air quality over time can be expected.

Because of the increasing concern over ammonia as a precursor for particulate matter and Philadelphia's location near a non-attainment area, it is important to consider a control system that can reduce emissions for gaseous ammonia. According to the EPA, the packed tower scrubber has an efficiency of 99% in removing ammonia.<sup>63</sup> With the scrubber however, ammonia would be transferred back to the liquid phase. This ammonia-concentrated water would then have to be sent to a biopond for further treatment before being released into the river. Pursuing a scrubber

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<sup>63</sup> Phillips, Jennifer. *Control and pollution prevention options for ammonia emissions*. No. PB-95-241790/XAB. VIGYAN, Inc., Vienna, VA (United States), 1995.

equipment would incur an additional \$50,000 in capital cost<sup>64</sup> for the scrubber and operating costs for water treatment. Ammonia control via the formation of ammonium phosphates was investigated but ultimately rejected due to the costs of separating, condensing, and reacting the ammonia, which would certainly be more than the \$60,000 worth of ammonia the process could produce annually (Appendix: A.1.4).

Another option is to simply recycle the contaminated air and use it as oxygen for the combustion of the natural gas. This option has several benefits over releasing it to the atmosphere. First, it avoids the costs mentioned above in case ammonia regulations become stricter. Secondly, it has environmental benefits. The addition of water and ammonia to the combustion of natural gas reduces the production of NO<sub>x</sub> gases,<sup>65</sup> one of the 6 Criteria Pollutants in the Clean Air Act.<sup>66</sup> The extract air stream being recycled to the combustion of natural gas would have both of these components (Table 15.1). Since natural gas requires 19 times as much air as methane, the hydrogen sulfide would be diluted by the excess air, and the ammonia would be introduced to reduce NO<sub>x</sub> formation. And if our refinery is burning 5.8 billion SCF methane per year, our annual air feed to the furnaces will be in excess of 100 billion SCF, far more air than is being used in our stripping process. The recycled air would be rich with ammonia and reduce the refinery's need to purchase outside ammonia.

Unlike using air as a stripping agent, there is only one destination option for the natural gas extract stream. If natural gas were used as the stripping agent, the extract stream would be directed back into the incoming natural gas stream to eventually be burned for heat in the refinery heaters.

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<sup>64</sup> Frederick, Andrew E, and Sarah. "Ammonia Scrubber Price." 5 Apr. 2018. Sarah is an ammonia scrubber saleswoman at Heil Process Equipment

<sup>65</sup> Nakhamkin, M., et al. *Combustion Studies of Natural Gas and Syn-Gas with Humid air*. Technical report, EPRI, Palo Alto CA, USA, 1994.

<sup>66</sup> "Criteria Air Pollutants." EPA, Environmental Protection Agency, 8 Mar. 2018, [www.epa.gov/criteria-air-pollutants](http://www.epa.gov/criteria-air-pollutants).

In 2016, refineries on the east coast used an average of 5,813,400,000 SCFY natural gas in their processes (Appendix: A.1.1).<sup>67</sup> The amount of natural gas required to strip the sour water in our design is 1,161,000,000 SCFY, which constitutes 20% of the total used by the refinery (Appendix: A.1.1).<sup>68</sup> Although the ammonia in the extract phase would be an average of 1670 ppm, it would be diluted to a concentration of 334 ppm of ammonia and 0.99 ppm of hydrogen sulfide once reintroduced to the refinery feed. The presence of ammonia and water vapor in the natural gas to be combusted work to reduce the amount of NO<sub>x</sub> produced in the fired heaters. While the presence of hydrogen sulfide in the natural gas to be burnt will react to form SO<sub>x</sub>, industrial fired heaters have systems in place to reduce the amount of SO<sub>x</sub> in the flue gas. Utility natural gas is considered sweet because it contains less than 8 ppm hydrogen sulfide, above which it is considered sour.<sup>69</sup> The average amount of hydrogen sulfide in the extract gas is under 5 ppm, and under 1 ppm after reintroduction to the feed natural gas. The amount of hydrogen sulfide introduced to the natural gas from the stripping process is less than the amount that the fired heater flue gas cleaning systems are designed to handle. Therefore, the natural gas stripping process would not contribute a significant amount of pollutants to the environment, and in fact would work to reduce NO<sub>x</sub> pollutants.

In recent years, east coast refineries have significantly increased their consumption of natural gas to higher levels than ever before.<sup>70</sup> The increase can be partially attributed to the

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<sup>67</sup> U.S. Energy Information Administration. "Fuel Consumed at Refineries." *East Coast (PADD 1) Fuel Consumed at Refineries*, U.S. Department of Energy, 21 June 2017, [www.eia.gov/dnav/pet/pet\\_pnp\\_capfuel\\_dcu\\_r10\\_a.htm](http://www.eia.gov/dnav/pet/pet_pnp_capfuel_dcu_r10_a.htm).

<sup>68</sup> U.S. Energy Information Administration. "Fuel Consumed at Refineries." *East Coast (PADD 1) Fuel Consumed at Refineries*, U.S. Department of Energy, 21 June 2017, [www.eia.gov/dnav/pet/pet\\_pnp\\_capfuel\\_dcu\\_r10\\_a.htm](http://www.eia.gov/dnav/pet/pet_pnp_capfuel_dcu_r10_a.htm).

<sup>69</sup> NaturalGas.org website page *Processing Natural Gas*.

<sup>70</sup> U.S. Energy Information Administration. "Fuel Consumed at Refineries." *East Coast (PADD 1) Fuel Consumed at Refineries*, U.S. Department of Energy, 21 June 2017, [www.eia.gov/dnav/pet/pet\\_pnp\\_capfuel\\_dcu\\_r10\\_a.htm](http://www.eia.gov/dnav/pet/pet_pnp_capfuel_dcu_r10_a.htm).

increase in natural gas production in the northeast from the Marcellus Shale, making natural gas more economical to purchase than other fuel sources for fueling steam boilers and other process units. The continued production of natural gas from shale in the northeast ensures that natural gas will continue to be used by refineries as a fuel, providing the natural gas stripping process with enough stripping agent to continue to be viable for the foreseeable future.

While the extract streams of the natural gas-fed and air-fed stripping columns have identical environmental consequences, the raffinate stream for a natural-gas fed stripping column has a slightly worse environmental impact. From Henry's Law, the sour water absorbs an average of 16 ppm when natural gas is used as the stripping agent. Concentrations of methane at this level are not harmful to the surrounding aquatic ecosystems.

In order to obtain a wastewater and air quality permit, fees must be paid to the state agency. For an air quality permit, the fees are \$5,300 for a permit application, \$375 for permit processing, and \$375/yr for operating fees.<sup>71</sup> For a wastewater permit, the fees are \$1,500 for a permit application and \$100 for every disturbed acre of land. Combined, the fees are \$7,475 in year 0 (assuming the sour water stripper technology will disturb 3 acres of land) and \$375 per year for operating costs.<sup>72</sup>

### **Section 23.2: Process Control Systems**

There are several control systems implemented in the sour water stripping process. They can all be seen in Section 15, in the Process Flow Diagrams (Figures 15.1 and 15.2). The level of detail given to the control system formulation is related to how specialized and integral it is in the

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<sup>71</sup> "Subchapter I. Plan Approval And Operating Permit Fees." *Pennsylvania Code*, [www.pacode.com/secure/data/025/chapter127/subchapItoC.html](http://www.pacode.com/secure/data/025/chapter127/subchapItoC.html).

<sup>72</sup> "The Pennsylvania Code." *Permit Applications and Fees.*, [www.pacode.com/secure/data/025/chapter102/s102.6.html](http://www.pacode.com/secure/data/025/chapter102/s102.6.html).

process. The blower and valve control computers and formulae are the most complex in the process, and very accurately calculate the amount of stripping agent required as a function of the feed sour water. The other four control systems, surge tank level, recycle, humidity, and temperature do not require as detailed or complex of a control system because they are less unique to the process, and they each depend on only one variable.

### **Section 23.2.1: Level Control System (T-100, M-100, LC, V-100)**

The Sour Water Surge Tank is fitted with a level meter, level controller, and control valve to maintain the height of liquid in the vessel. The height of liquid in the tank will be maintained at 80% capacity with a proportional controller. This amount of liquid equates to nearly an hour (0:53:20) of holdup, and is low enough that it would take 10 minutes of maximum flow, and no control system action, to overflow the tank.

### **Section 23.2.2: Recycle Control System (M-100, RC, S-100, T-100)**

The recycle control system is engaged when the sour water flow rate at the flow meter drops below the set point value of 30 GPM, the minimum flow rate in the column before tray weeping occurs. This will activate the splitter valve on the raffinate to return enough water back to the surge tank to bring the sour water flow back up to 30 GPM. While this control system is engaged, the Blower Control Computer (or Valve Control Computer) will ignore pH Meter 1, and will calculate the amount of stripping agent required based on the sour water flow rate, and assuming an ammonia concentration of 3000 ppm. This is because the pH Meter will give readings influenced by more dissolved components than just ammonia, so the ammonia concentration calculation will be incorrect.

### Section 23.2.3: Blower Control System (M-101, M-102, BC | CP, B-100)

The feed forward blower control system calculates and specifies the amount of air required to strip the sour water given the flow rate and ammonia concentration. From 9 combinations of ASPEN inputs and outputs, calculated at minimum, average, and maximum values for both input variables (Appendix: A.2.3), an equation (Equation 18.1) was fit to the data to yield an air flow rate at least as high as the minimum simulation flow rate. Calculations were made using the qualities (density, temperature, etc.) of sour water at the measurement conditions Stream 2 (Figure 15.1), and estimates the amount of air needed with an overshoot between 0.04% and 3.24%. The equation has a small overshoot buffer so that the water will never be stripped to less-than-required specifications, although a calculated value marginally below the required air would not be an issue because the specifications in ASPEN are to 19 ppm instead of 20, giving a small buffer zone if the amount of air fed to the column is slightly too low. Below is Equation 18.1:

$$V = \left( \left( \sqrt{C} * \frac{FF}{24} + \frac{(15000-FF)}{12.5} - 330 * \left(\frac{C}{300}\right)^{1.5} + 555 + (FF - 20000) * 0.026 \right) * \left(\frac{300}{C}\right)^{0.2} + \left(\frac{C}{300}\right)^{\frac{1}{3}} + \left(\frac{29}{FF} * \frac{C}{4}\right)^{19.15} + \left(\left(\frac{15000}{FF}\right)^{0.1} * \frac{C}{3}\right) + \frac{16000-FF}{1.25} + \left(\frac{300}{C}\right)^3 * 58 * \frac{FF-14000}{115} + abs\left|\frac{FF-19100}{4.3}\right| \right) * 0.8802,$$

where **V** is the air flow required in lb/hr, **C** is the concentration of ammonia in ppm, and **FF** is the feed sour water flow rate in lb/hr (or 498.65\*GPM at flowmeter conditions). This feed-forward control equation will be utilized by the blower control computer to set the blower to the appropriate specification based on the sour water flow rate.

Figures 23.1 and 23.2 below represent the surface created by graphing the blower control equation (Equation 18.1). The axes on the horizontal plane represent the variability of the sour water flow rate (right horizontal axis) and the variability of sour water ammonia concentration (left horizontal axis). The vertical axis represents the amount of stripping agent (air) required to



satisfactorily purify the sour water at a given point on the horizontal plane. The color bars represent the amount of stripping agent required in lb/hr. In figure 23.1, the turned-up corners indicate that the control equation is not ideally optimized, but the buffer systems in place (overestimation of control equation, and specification for 19 ppm ammonia) work to ensure that enough air is being provided to the stripping process. This 3D representation of the equation surface shows the complexity of the control equation, and how complicated the relationship of the sour water variables are to the amount of stripping agent required.

**Figure 23.1:** 3D Representation of the Equation 18.1 Surface for Air Stripping. Color bar in units of lb/hr.

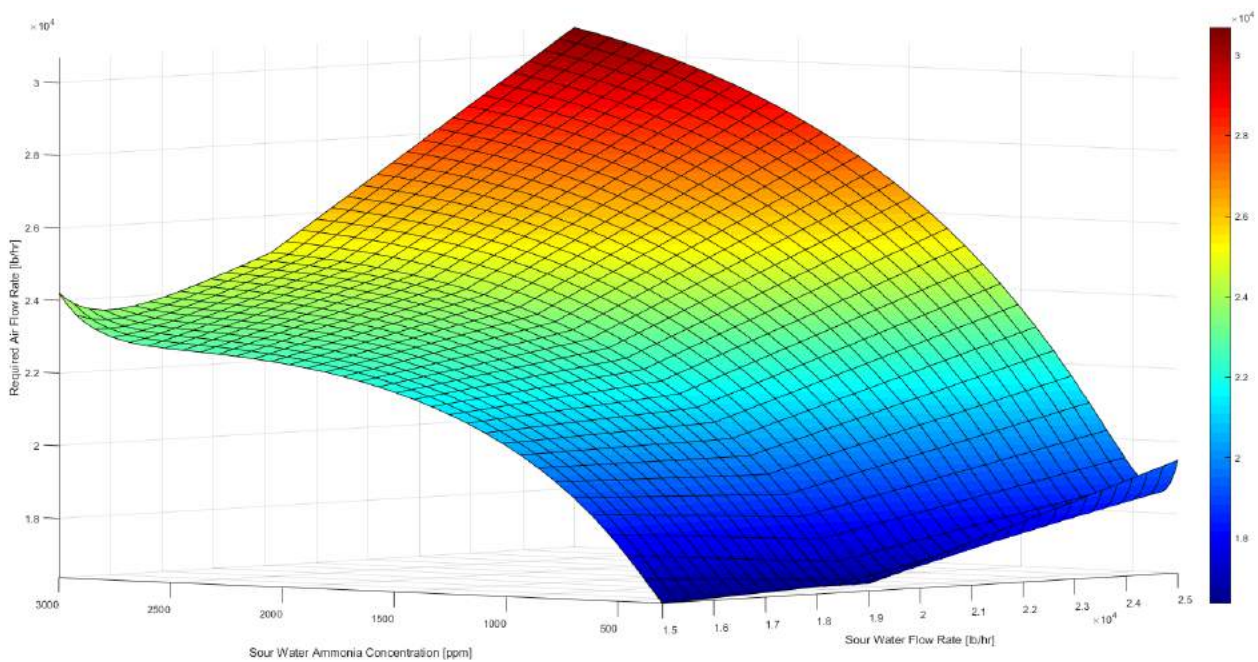
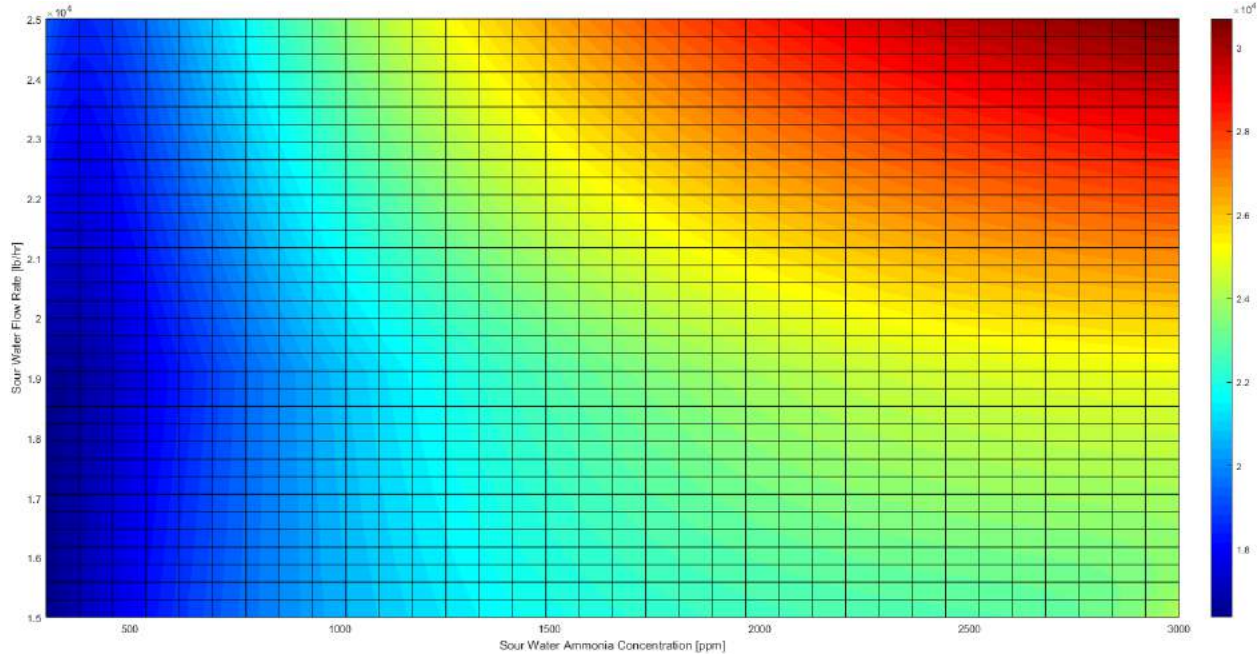


Figure 23.2 shows a top-down view of the control equation surface. While less complex, this figure more clearly shows the trends of the relationships. The color bar shows the amount of stripping agent required in units of lb/hr.

**Figure 23.2:** 2D Representation of Equation 18.1 Surface for Air Stripping. Color bar in units of lb/hr.



#### Section 23.2.4: Valve Control System (M-101, M-102, VC | CP, V-101)

The feed forward valve control system calculates and specifies the amount of natural gas required to strip the sour water given the flow rate and ammonia concentration. From 9 combinations of ASPEN inputs and outputs, calculated at minimum, average, and maximum values for both input variables (Appendix: A.2.3) an equation (Equation 18.2) was fit to the data to yield a natural gas flow rate at least as high as the minimum simulation flow rate. Calculations were made using the qualities (density, temperature, etc.) of sour water at the measurement conditions Stream 2 (Figure 15.2), and estimates the amount of natural gas needed with an overshoot between 0.01% and 3.17%. The equation has a small overshoot buffer so that the water will never be stripped to less-than-required specifications, although a calculated value marginally below the required natural gas would not be an issue because the specifications in ASPEN are to

19 ppm instead of 20, giving a small buffer zone if the amount of air fed to the column is slightly too low. Below is Equation 18.2:

$$V = \left( \left( \left( \left( \frac{C*FF}{1500} + \frac{15000-FF}{12.5} - 330 * \left( \frac{C}{300} \right)^{1.5} + 330 + (1000 - C) * 6 * \left( \frac{FF-17200}{10000} \right) \right) + 6065 \right) * 0.96 - \left( \frac{15000}{FF} \right)^{1.5} * C * 5 + \frac{(900-C)*FF}{20000} - abs|1600 - C| * \left( \frac{FF}{27000} \right)^3 + \left( \frac{15000}{FF} \right)^4 * 3300 + \frac{C}{3} * \frac{25000}{FF} \right) * \frac{(14 + \frac{300}{C})}{14.3},$$

where **V** is the natural gas flow required in lb/hr, **C** is the concentration of ammonia in ppm, and **FF** is the feed sour water flow rate in lb/hr (or 498.65\*GPM at flowmeter conditions). This feed-forward control equation will be utilized by the valve control computer to set the blower to the appropriate specification based on the sour water flow rate.

Figures 23.3 and 23.4 below represent the surface created by graphing the valve control equation (Equation 18.2). The axes on the horizontal plane represent the variability of the sour water flow rate (right horizontal axis) and the variability of sour water ammonia concentration (left horizontal axis). The vertical axis represents the amount of stripping agent (natural gas) required to satisfactorily purify the sour water at a given point on the horizontal plane. The color bars represent the amount of stripping agent required in lb/hr. In figure 23.3, the smooth contours of the surface indicate that the control system is well-optimized for the entire range of inputs. This 3D representation of the equation surface shows the complexity of the control equation, and how complicated the relationship of the sour water variables are to the amount of stripping agent required.

**Figure 23.3:** 3D Representation of the Equation 18.2 Surface for Natural Gas Stripping. Color bar in units of lb/hr.

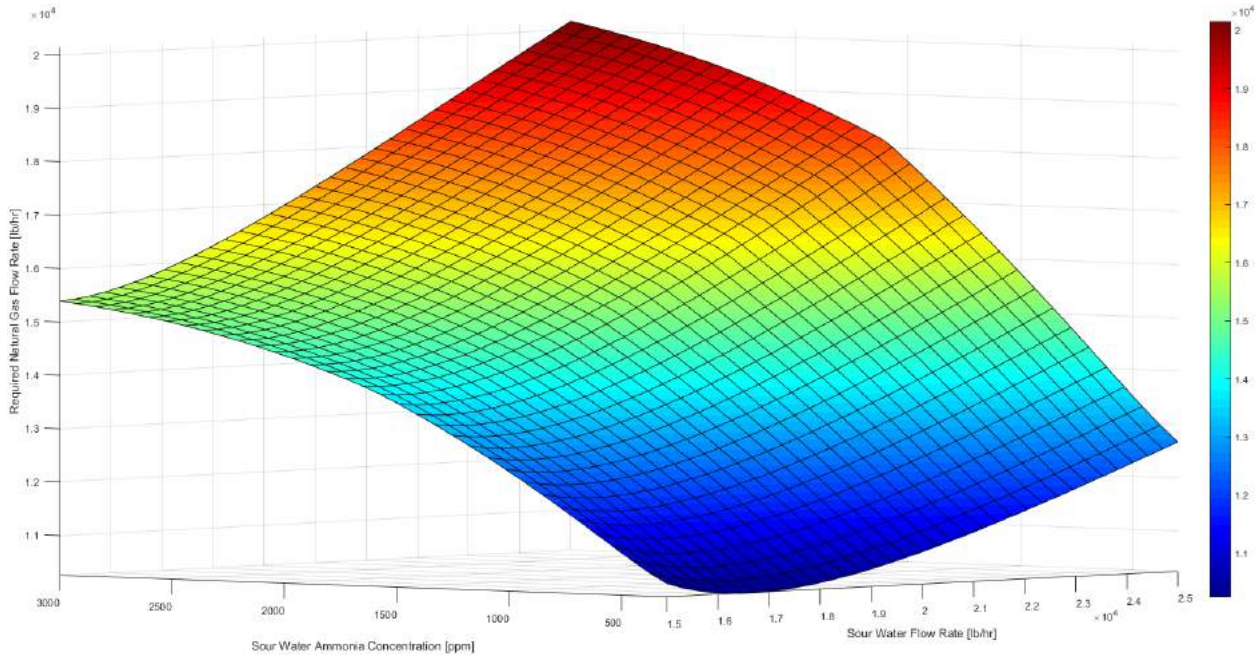
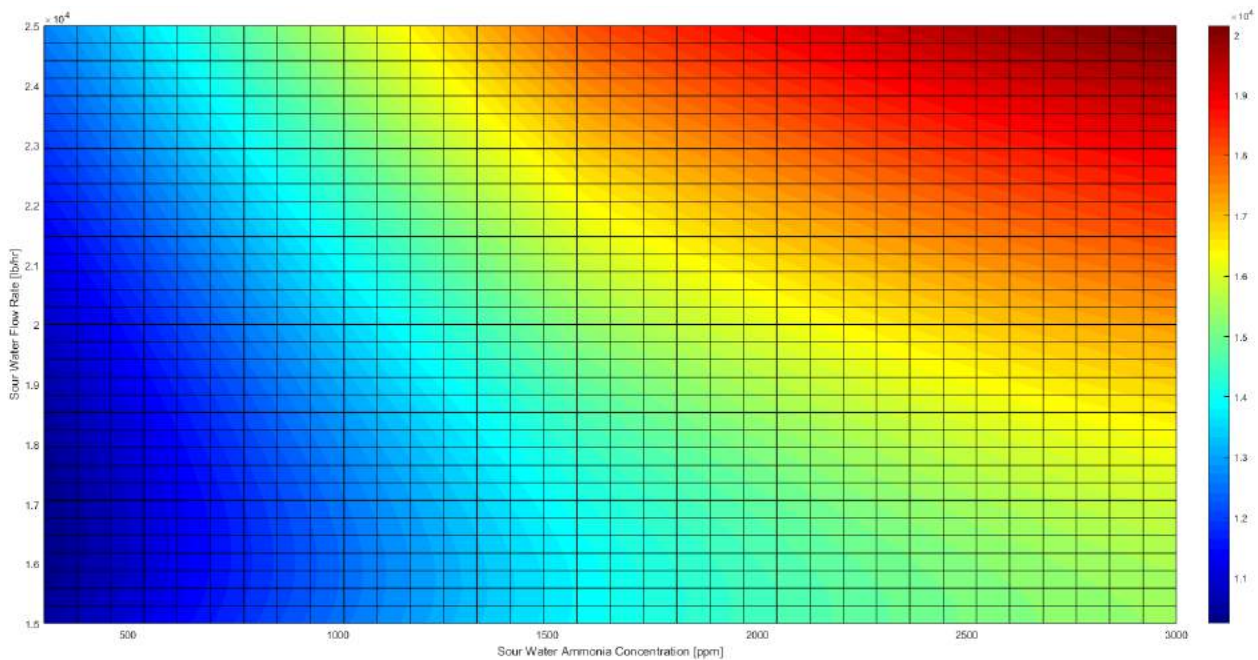


Figure 23.4 shows a top-down view of the control equation surface. While less complex, this figure more clearly shows the trends of the relationships. The color bar shows the amount of stripping agent required in units of lb/hr.

**Figure 23.4:** 2D Representation of Equation 18.2 Surface for Natural Gas Stripping. Color bar in units of lb/hr.



**Section 23.2.5: Humidity Control System (M-104, HC, I-100)**

The feedback humidity control system regulates how much steam is injected into the stripping agent gas stream to maintain a water vapor concentration of 10% by mass in the stripping agent fed to the column.

**Section 23.2.6: Temperature Control System (M-105, TC, F-101)**

The feedback temperature control system regulates the heat duty of the fired heater to maintain a temperature of 190°F in the stripping agent fed to the column

**Section 23.3: Safety and Health Concerns**

Ammonia and hydrogen sulfide are dangerous to humans in the gaseous phase. As mentioned above, the OSHA 8 hour limit exposure limit to ammonia and hydrogen sulfide is 25 ppm and 1 ppm respectively. Exposure to 300 ppm of ammonia 100 ppm of hydrogen sulfide is immediately dangerous to life and health according to the National Institute for Occupational Safety and Health (NIOSH). Because such workplace limits are set, continuously monitoring devices must be installed to alert the operators of unsafe conditions.

Operators must be equipped with personal protective equipment (PPE) to prevent harmful encounters with the chemicals. This PPE includes wearing gloves and clothing that cannot be permeated or degraded by hydrogen sulfide, wearing non-vented, impact resistant goggles, and a full facepiece powered-air purifying respirator if levels of hydrogen sulfide reach greater than 1 ppm or if levels of ammonia reach greater than 25 ppm. Because the gases are irritants to eyes and skin, eyewashes and showers must be available on the floor in case of emergencies. In the case of spills or leaks, the immediate area will be ventilated to disperse the gases. Additionally,

carbon dioxide fire extinguishers must be handy to put out potential fire caused by hydrogen sulfide.

Accidental large scale releases of ammonia due to equipment malfunction or failure have caused major problems in the past. In August of 2010, a refrigeration warehouse released 32,000 pounds of ammonia from a cracked pipe. The ammonia travelled over a shipyard that caused 152 people to be treated at hospitals. These large scale releases can also be costly. The EPA required third party audits to conduct pipe testing and test for compliance at Tyson Foods following multiple violations and a large scale leak at the plant, costing Tyson Foods \$3.95 million.<sup>73</sup> To mitigate these accidental release, the EPA requires plants to implement a Risk Management Program. Emitting more than 10,000 pounds<sup>74</sup> of ammonia through a leak violates 40 CFR part 68, the chemical accident prevention provision. To avoid these catastrophic failures, the refinery is responsible for assessing the potential release impacts, steps to prevent releases, and a plan for emergency response to releases.

If natural gas were used as the stripping agent instead of air, additional safety precautions would have to be taken. While methane can cause irritation when inhaled, its direct threat to human safety is that it decreases the amount of oxygen in the air when present in large amounts. For this reason, careful monitoring must be done to ensure that there is a minimum of 19.5% oxygen concentration by volume. An additional danger of using methane over air is that it is highly flammable. For this reason, it is important to avoid accumulation of gas above the lower explosive limit (LEL) which is 5%. Additionally, since the natural gas feed pressure is 500 psig, the area between the utility source and the natural gas control valve must be demarcated as a high

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<sup>73</sup> “40 CFR Part 68.” *Environmental Protection Agency: Accidental Release Prevention Program*, vol. 81, no. 49, 14 Mar. 2016.

<sup>74</sup> “40 CFR Part 68.” *Environmental Protection Agency: Accidental Release Prevention Program*, vol. 81, no. 49, 14 Mar. 2016. Appendix A

pressure zone. To mitigate the risk associated with using natural gas as the stripping agent, some safety precautions should be installed. These include continuously monitoring leak devices to check for any methane leaks, gas sampling to ensure quality of natural gas and indicate corrosion of pipe, and the removal of any possible ignition sources near the natural gas source.

Another general safety concern involves water above scalding temperature. To control the threat of this hot water, the sour pump heater will be isolated and caged to prevent operators from coming too close. Administrative “warning” signs will also be placed nearby to indicate the danger of hot surfaces.<sup>75</sup>

One preventative measure to ensure proper the functioning of measuring devices is the installation of duplicate pH meters and thermocouples. These devices are susceptible to corrosion and declining performance over time. Having two of each device will alert the operators of any malfunctions and ensure proper readings.

#### **Section 23.4: Boiler Feed Water (BFW) Considerations**

The use of the raffinate, or sweet water, as Boiler Feed Water was considered and ultimately rejected. Boiler Feed Water is typically bought from the utilities at \$5/1000 gallons and used as steam generation from the boilers. Boilers require ammonia and hydrogen sulfide concentrations below detectable limits, or less than 0.1 ppm.<sup>76</sup> Stripping the ammonia concentrations to below 0.1 ppm would require a bigger column, the price of which would be far from covered by the \$5 savings per 1000 gallons. Rather than stripping the ammonia to 0.1 ppm, it was proposed that the effluent raffinate stream could be sent to a biopond for further purification.

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<sup>75</sup> “Critical Risk: Hot Water and Steam.” *MINTRAC and AMPC*, June 2014.

<sup>76</sup> Frederick, Andrew E, and Tyler McDevitt. “Sour Water Process Engineer Consultation.” 12 Apr. 2018. Tyler is a process engineer at Phillips 66 refinery.

The transportation alone to and from the pond would exceed \$5/1000 gallons, not to mention the cost of the treatment itself. In the end, it is not economically viable to reuse the raffinate as boiler feed water.



Section 24

# **Profitability Analysis – Business Case**

For the air stripping process, of \$2.00 MM total capital investment, \$0.23 MM is the present value of the working capital at 15% nominal interest rate. This working capital is composed of cash reserves and accounts payable for purchasing raw materials. On the other hand, of the \$1.4 MM total capital investment of the natural gas stripping process, \$0.25 MM is the present value of the working capital at 15% nominal interest rate and has the same composition as in the air stripping process.

Our team estimated the value of this project over a nineteen-year lifespan. The first year is allocated to process design and the second year to construction. For the lifespan of this project, the stripping process will be carried out at 100% of design capacity and it will be started at 100% of production capacity. This is because, as the main objective of this project is to strip ammonia and hydrogen sulfide from sour water to the acceptable concentrations, the process can't be carried out at a percentage of design capacity less than 100% because then the acceptable concentrations would not be reached.

**Table 24.1.** Working Capital Requirements for the Air Stripping Process<sup>77</sup>

<b>Working Capital</b>				
	<b>2019</b>	<b>2020</b>	<b>2021</b>	
Accounts Receivable	\$ -	\$ -	\$ -	-
Cash Reserves	\$ 286,776	\$ -	\$ -	-
Accounts Payable	\$ (25,079)	\$ -	\$ -	-
Sweet water Inventory	\$ -	\$ -	\$ -	-
Raw Materials	\$ 11	\$ -	\$ -	-
<b>Total</b>	<b>\$ 261,708</b>	<b>\$ -</b>	<b>\$ -</b>	<b>-</b>
<i>Present Value at 15%</i>	<i>\$ 227,572</i>	<i>\$ -</i>	<i>\$ -</i>	<i>-</i>
<b><u>Total Capital Investment</u></b>		<b>\$ 2,003,110</b>		

<sup>77</sup> Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).

**Table 24.2.** Working Capital Requirements for the Natural Gas Stripping Process<sup>78</sup>

<b>Working Capital</b>						
	<b>2019</b>		<b>2020</b>		<b>2021</b>	
Accounts Receivable	\$	-	\$	-	\$	-
Cash Reserves	\$	277,271	\$	-	\$	-
Accounts Payable	\$	(605,482)	\$	-	\$	-
Sweet water Inventory	\$	-	\$	-	\$	-
Raw Materials	\$	39,250	\$	-	\$	-
<b>Total</b>	<b>\$</b>	<b>(288,961)</b>	<b>\$</b>	<b>-</b>	<b>\$</b>	<b>-</b>
<i>Present Value at 15%</i>	\$	(251,271)	\$	-	\$	-
<b>Total Capital Investment</b>			<b>\$</b>	<b>1,392,353</b>		

Table 24.3 and Table 24.4 show the profitability metrics of the stripping process using air and natural gas respectively in the third year, even though the first year the plant will already be operating at full capacity. The net present value (NPV) for the 19 years of the air stripping process is -\$16 MM with an ROI of -135.81% compared to -\$15 MM with a ROI of -197.17% for the natural gas stripping process. The NPV and ROI are both negative because this project is not generating any revenue as mentioned in Section 22.1. The air stripping process’s NPV is \$1 MM more than that of the natural gas stripping process because the operating costs of the air stripping process are more than those of the natural gas stripping process as seen in Section 22.

<sup>78</sup> Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).

**Table 24.3.** Profitability measures for the Air Stripping Process<sup>79</sup>

Profitability Measures	
<b>The Internal Rate of Return (IRR) for this project is</b>	Negative IRR
<b>The Net Present Value (NPV) of this project in 2018 is</b>	\$ (15,857,500)
<b>ROI Analysis (Third Production Year)</b>	
Annual Sales	-
Annual Costs	(3,498,559)
Depreciation	(142,043)
Income Tax	873,744
Net Earnings	<u>(2,766,858)</u>
Total Capital Investment	<u>2,037,246</u>
ROI	-135.81%

**Table 24.4.** Profitability Measures for the Natural Gas Stripping Process<sup>80</sup>

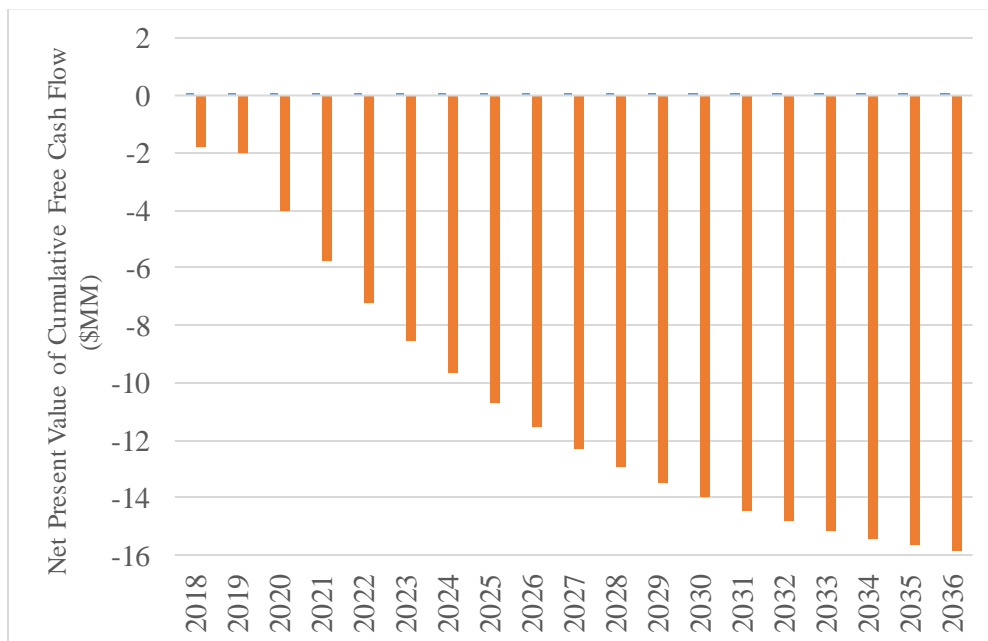
Profitability Measures	
<b>The Internal Rate of Return (IRR) for this project is</b>	Negative IRR
<b>The Net Present Value (NPV) of this project in 2018 is</b>	\$(14,836,900)
<b>ROI Analysis (Third Production Year)</b>	
Annual Sales	-
Annual Costs	(3,382,886)
Depreciation	(131,490)
Income Tax	843,450
Net Earnings	<u>(2,670,925)</u>
Total Capital Investment	<u>1,354,663</u>
ROI	-197.17%

<sup>79</sup> Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).

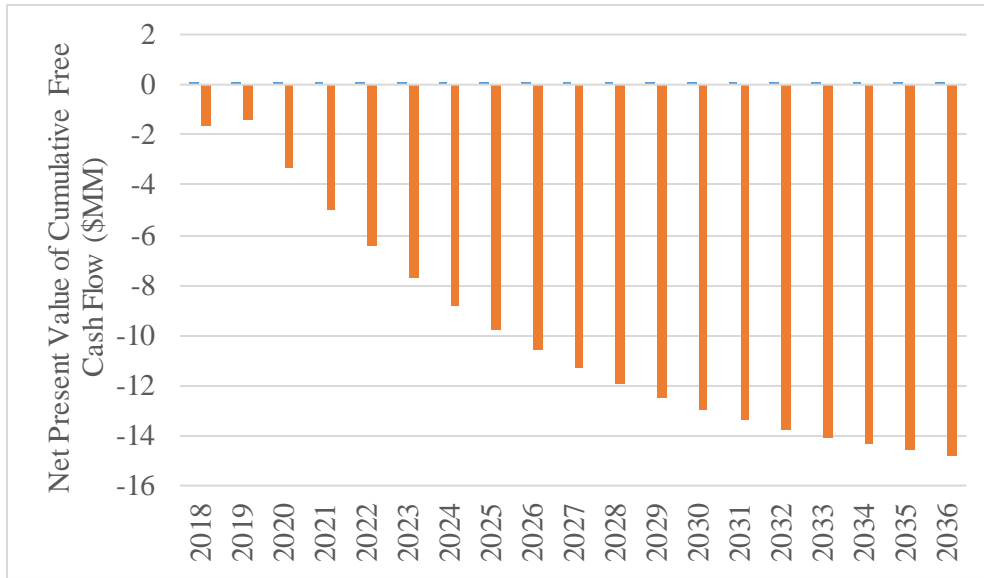
<sup>80</sup> Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).

The following graphics show the value of the air and natural gas stripping processes in millions of 2018 U.S. dollars over time. Over the first 2 years, the cash flow is a more negative number because both stripping processes are at 0% design capacity and these costs can be attributed to design and construction of each process. In 2020, both processes are at 100% design capacity and the variable and fixed costs related to the stripping processes start to be incurred. This explains why the cash flows become a greater negative number beginning 2020 and increases constantly until the end of the useful life of the project. The cumulative cash flow for the air stripping process is more negative than that for the air stripping process because, as mentioned earlier, there is a difference in the operating costs. This becomes more pronounced since these are cumulative cash flows.

**Figure 24.1.** Cumulative discounted free cash flow (\$MM) for the air stripping process over nineteen-year lifespan. The process assume no product is being sold and production starts in 2020 after 2 years of design and construction.



**Figure 24.2.** Cumulative discounted free cash flow (\$MM) for the natural gas stripping process over nineteen-year lifespan. The process assume no product is being sold and production starts in 2020 after 2 years of design and construction.



The following cash flow summary sheets assume a 20-year MACRS depreciation schedule for the air and natural gas stripping processes. Additionally, annual tax assets were added for each year net operating loss was incurred.

**Table 24.5:** Cash Flow Summary for the Air Stripping Process

Year	Percentage of Design Capacity	Cash Flow Summary											Cumulative Net Present Value at 15%	
		Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxable Income	Taxes	Net Earnings	Cash Flow			
2018	0%	(1,775,500)	-	-	-	-	-	-	-	-	-	-	(1,775,500)	(1,775,500)
2019	0%	-	(261,700)	-	-	-	-	-	-	-	-	-	(261,700)	(2,003,100)
2020	100%	-	-	(312,600)	(3,186,000)	(59,400)	-	(3,558,000)	853,900	(2,704,100)	(2,644,600)	(2,644,600)	(4,002,800)	
2021	100%	-	-	(312,600)	(3,186,000)	(114,400)	-	(3,613,000)	867,100	(2,745,900)	(2,631,400)	(2,631,400)	(5,733,000)	
2022	100%	-	-	(312,600)	(3,186,000)	(105,900)	-	(3,604,400)	865,100	(2,739,400)	(2,633,500)	(2,633,500)	(7,238,800)	
2023	100%	-	-	(312,600)	(3,186,000)	(97,900)	-	(3,596,500)	863,200	(2,733,300)	(2,635,400)	(2,635,400)	(8,549,000)	
2024	100%	-	-	(312,600)	(3,186,000)	(90,600)	-	(3,589,100)	861,400	(2,727,700)	(2,637,200)	(2,637,200)	(9,689,100)	
2025	100%	-	-	(312,600)	(3,186,000)	(83,800)	-	(3,582,300)	859,800	(2,722,600)	(2,638,800)	(2,638,800)	(10,681,200)	
2026	100%	-	-	(312,600)	(3,186,000)	(77,500)	-	(3,576,000)	858,300	(2,717,800)	(2,640,300)	(2,640,300)	(11,544,300)	
2027	100%	-	-	(312,600)	(3,186,000)	(71,700)	-	(3,570,200)	856,900	(2,713,400)	(2,641,700)	(2,641,700)	(12,295,200)	
2028	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(12,948,300)	
2029	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(13,516,100)	
2030	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(14,009,900)	
2031	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(14,439,300)	
2032	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(14,812,700)	
2033	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(15,137,400)	
2034	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(15,419,700)	
2035	100%	-	-	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,641,900)	(2,641,900)	(15,665,200)	
2036	100%	-	261,700	(312,600)	(3,186,000)	(70,700)	-	(3,569,300)	856,600	(2,712,700)	(2,380,200)	(2,380,200)	(15,857,500)	

**Table 24.6:** Cash Flow Summary for the Natural Gas Stripping Process

Year	Percentage of Design Capacity	Cash Flow Summary											Cumulative Net Present Value at 15%	
		Capital Costs	Working Capital	Var. Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxable Income	Taxes	Net Earnings	Cash Flow			
2018	0%	(1,643,600)	-	-	-	-	-	-	-	-	-	-	-	(1,643,600)
2019	0%	-	289,000	-	-	-	-	-	-	-	-	-	-	289,000
2020	100%	-	-	(213,000)	(3,169,900)	(55,000)	-	(3,437,900)	825,100	(2,612,800)	(2,557,800)	(2,557,800)	(3,326,400)	
2021	100%	-	-	(213,000)	(3,169,900)	(105,900)	-	(3,488,800)	837,300	(2,651,500)	(2,545,600)	(2,545,600)	(5,000,200)	
2022	100%	-	-	(213,000)	(3,169,900)	(98,000)	-	(3,480,900)	835,400	(2,645,500)	(2,547,500)	(2,547,500)	(6,456,700)	
2023	100%	-	-	(213,000)	(3,169,900)	(90,600)	-	(3,473,500)	833,600	(2,639,900)	(2,549,200)	(2,549,200)	(7,724,100)	
2024	100%	-	-	(213,000)	(3,169,900)	(83,800)	-	(3,466,700)	832,000	(2,634,700)	(2,550,900)	(2,550,900)	(8,826,900)	
2025	100%	-	-	(213,000)	(3,169,900)	(77,600)	-	(3,460,400)	830,500	(2,629,900)	(2,552,400)	(2,552,400)	(9,786,500)	
2026	100%	-	-	(213,000)	(3,169,900)	(71,700)	-	(3,454,600)	829,100	(2,625,500)	(2,553,800)	(2,553,800)	(10,621,300)	
2027	100%	-	-	(213,000)	(3,169,900)	(66,400)	-	(3,449,200)	827,800	(2,621,400)	(2,555,100)	(2,555,100)	(11,347,600)	
2028	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,800)	(2,555,300)	(2,555,300)	(11,979,200)	
2029	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,700)	(2,555,300)	(2,555,300)	(12,528,500)	
2030	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,800)	(2,555,300)	(2,555,300)	(13,006,100)	
2031	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,700)	(2,555,300)	(2,555,300)	(13,421,400)	
2032	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,800)	(2,555,300)	(2,555,300)	(13,782,500)	
2033	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,700)	(2,555,300)	(2,555,300)	(14,096,500)	
2034	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,800)	(2,555,300)	(2,555,300)	(14,369,600)	
2035	100%	-	-	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,700)	(2,555,300)	(2,555,300)	(14,607,100)	
2036	100%	-	(289,000)	(213,000)	(3,169,900)	(65,500)	-	(3,448,400)	827,600	(2,620,800)	(2,844,200)	(2,844,200)	(14,836,900)	



Section 25

# Conclusions and Recommendations

Based on thorough analyses of the economic, environmental, and health and safety viability of the designs using air and natural gas as stripping agents, it is recommended that the refinery pursues both designs as potential alternatives to the traditional steam stripping processes. Both designs were compared on the basis of stripping ammonia and hydrogen sulfide to raffinate concentrations of 20 ppm and 0.1 ppm respectively. Compared to the air design, the natural gas design is superior with respect to economics and stripping efficiency, equivalent with respect to extract gas environmental impact, and slightly worse with respect to health and safety concerns and wastewater environmental impact.

Both designs were optimized to lower the capital cost of the equipment; and the total capital investment of the natural gas stripping process was \$1.6 MM compared to \$1.8 MM for air. Additionally, the NPV of the design with natural gas as the stripping agent is -\$15 MM compared to the NPV of air as the stripping agent which is -\$16 MM. These numbers are based on a large number of assumptions and calculations listed in Section 22 and Section 24 which should be revisited to confirm their accuracy.

Rather than releasing the extract gas into the atmosphere, it is recommended that the extract gases for both stripping processes are recycled to the furnaces: as fuel in the case of natural gas, and as oxygen-containing air required for combustion in the case of air. Doing so has two benefits. First, it avoids the capital expenditure needed for ammonia control equipment in the likely case that ammonia regulations become stricter. Second, the ammonia and water in the extract stream reduce the amount of  $\text{NO}_x$  produced in the combustion of natural gas. Recycling the extract stream to the refinery burners results in nearly identical environmental consequences for both air and natural gas as stripping agents.

Another difference between natural gas and air stripping to consider is the contamination of the raffinate water. Compared to air as a stripping agent, which does not further contaminate the sour water, the use of natural gas as a stripping agent leads to the addition of 17 ppm methane in the produced sweeter water (Table 15.3).

The final consideration for the endorsement of one design over the other is the safety of each design. Using natural gas as the stripping agent requires additional safety precautions compared to using air. Such safety precautions include carefully monitoring the oxygen concentration of the ambient inside air to protect against reduction by methane, having leak monitoring devices since methane is highly flammable and odorless, and demarcating the piping from the natural gas feed to the depressurizing control valve as a high pressure zone.

Given that the use of air and natural gas have equivalent trade-offs, namely the slightly lower environmental impact of air, the manageable health and safety concerns of natural gas, and the minor economic advantages of natural gas, both processes are recommended for further investigation. This further investigation should include a rigorous comparison to the industry standard, steam stripping, to determine if the novel processes have any economic, environmental, or health and safety benefits versus steam stripping.

Section 26  
**Acknowledgements**

Our team would like to thank Dr. Allen and Professor Vrana for their constant support. We are extremely grateful that Dr. Allen provided guidance in our weekly meetings to make sure we moved in the right direction. We would like to thank Professor Vrana for helping us with our process development and economics. He provided help on column internals in order to accurately model the air and natural gas stripping processes. He also provided tremendous help in deciding what our economic analysis should be based on since we are not producing any product that is going to be sold. Their advice was very helpful and helped us stay on track.

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Section 27  
**Bibliography**

1. "18 CFR Part 410." *Delaware River Basin Commission*, 4 Dec. 2013, p. 111.
2. "2014 National Emissions Inventory (NEI) Data." *EPA*, Environmental Protection Agency, 2 Mar. 2018, [www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data](http://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data).
3. "40 CFR Part 68." *Environmental Protection Agency: Accidental Release Prevention Program*, vol. 81, no. 49, 14 Mar. 2016.
4. "40 CFR Part 68." *Environmental Protection Agency: Accidental Release Prevention Program*, vol. 81, no. 49, 14 Mar. 2016. Appendix A
5. Addington, Luke, et al. "Sour water: Where it comes from and how to handle it." *Bryan Research and Engineering Inc.* [online]. *Disponibile en: <https://www.bre.com/PDF/Sour-Water-Where-It-Comes-from-and-How-to-Handle-It.pdf>* (2011).
6. "Agricultural Air Pollution Fact Sheet." *Texas A&M Center for Agricultural Air Quality Engineering & Science*.
7. "Ammonia Acute Exposure Guideline Levels." *Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 6.*, U.S. National Library of Medicine, 1 Jan. 1970, [www.ncbi.nlm.nih.gov/books/NBK207883](http://www.ncbi.nlm.nih.gov/books/NBK207883)
8. Baise, Gary. "More EPA Regulation of Ammonia?" *Farm Futures*, 6 Oct. 2016, [www.farmfutures.com/blogs-more-epa-regulation-ammonia-9456](http://www.farmfutures.com/blogs-more-epa-regulation-ammonia-9456).
9. "Clean Water Act, Section 502 General Definitions." *EPA*, Environmental Protection Agency, 15 Sept. 2016, [www.epa.gov/cwa-404/clean-water-act-section-502-general-definitions](http://www.epa.gov/cwa-404/clean-water-act-section-502-general-definitions).
10. "Criteria Air Pollutants." *EPA*, Environmental Protection Agency, 8 Mar. 2018, [www.epa.gov/criteria-air-pollutants](http://www.epa.gov/criteria-air-pollutants).
11. "Critical Risk: Hot Water and Steam." *MINTRAC and AMPC*, June 2014.
12. "CWA Section 404 Enforcement Overview." *EPA*, Environmental Protection Agency, 17 Nov. 2017, [www.epa.gov/cwa-404/cwa-section-404-enforcement-overview](http://www.epa.gov/cwa-404/cwa-section-404-enforcement-overview).
13. Downey, B. K., *Profitability Analysis Spreadsheet*, University of Pennsylvania, Philadelphia (2008).
14. Engineering ToolBox, "Water Vapor and Saturation Pressure in Humid Air." *Water Vapor and Saturation Pressure in Humid Air*, 2004, [www.engineeringtoolbox.com/water-vapor-saturation-pressure-air-d\\_689.html](http://www.engineeringtoolbox.com/water-vapor-saturation-pressure-air-d_689.html).
15. Frederick, Andrew E, and Edward Wiener. "Emission Limits of Ammonia in Philadelphia." 16 Apr. 2018. Edward is an Environmental Engineer for Philadelphia Air Management Services.
16. Frederick, Andrew E, and Leonard Fabiano. "Column Design in ASPEN." 8 Mar. 2018. Leonard is an adjunct Professor at the University of Pennsylvania
17. Frederick, Andrew E, and Robert Schlosser. "Emission Limit for Ammonia." 12 Apr. 2018. Robert is a Principal Project Manager at IES Engineers
18. Frederick, Andrew E, and Sarah. "Ammonia Scrubber Price." 5 Apr. 2018. Sarah is an ammonia scrubber saleswoman at Heil Process Equipment
19. Frederick, Andrew E, and Tyler McDevitt. "Sour Water Process Engineer Consultation." 12 Apr. 2018. Tyler is a process engineer at Phillips 66 refinery.
20. Harvey, Fiona. "Ammonia Emissions Rise in UK, ." *The Guardian*, Guardian News and Media, 16 Feb. 2018, [www.theguardian.com/environment/2018/feb/15/ammonia-emissions-rise-air-pollutants-fall-new-government-statistics](http://www.theguardian.com/environment/2018/feb/15/ammonia-emissions-rise-air-pollutants-fall-new-government-statistics).
21. Hatcher, Nathan, and Ralph Weiland. "Reliable design of sour water strippers." *Petroleum Technology Quarterly* 17.4 (2012): 83.
22. *Health Effects Information: Ammonia*. Public Health Office, 2000, *Health Effects Information: Ammonia*.
23. "Historic Average, Philadelphia, Pennsylvania." *Intellicast - Philadelphia Historic Weather Averages in Pennsylvania (19113)*, TWC Product and Technology, LLC, 2018,
24. "Key Federal Laws: Clean Water Act." *Chem Alliance*, 2016, [www.chemalliance.org/tools/?subsec=25&id=6922](http://www.chemalliance.org/tools/?subsec=25&id=6922)
25. Leach, Connor T, and Michael Dowdy. "PH Meter Delay Time for Step Input." 13 Mar. 2018. Michael is a sales representative for Cemtech Energy Controls, Inc., the Philadelphia sales representative company for Yokogawa Corporation of America.



26. Lee, D., et al. "Dynamic simulation of the sour water stripping process and modified structure for effective pressure control." *Chemical Engineering Research and Design* 80.2 (2002): 167-177.
27. Mackenzie, Patricia Denise, and C. J. King. "Simultaneous stripping and solvent extraction for the recovery of ammonia and acid gases from wastewaters." (1984).
28. Mathias, Scott. "Managing Air Quality: State Implementation Plans." U.S. EPA, 3 Oct. 2007.
29. McAngus, Jess. *Refinery Air Emission Metrics*. Spirit Environmental, LLC, 2013, *Refinery Air Emission Metrics*.
30. Nakhamkin, M., et al. *Combustion Studies of Natural Gas and Syn-Gas with Humid air*. Technical report, EPRI, Palo Alto CA, USA, 1994.
31. "Natural Gas – From Wellhead to Burner Tip." *NaturalGas.org*, NaturalGas.Org, 20 Sept. 2013, [naturalgas.org/naturalgas/](http://naturalgas.org/naturalgas/).
32. NaturalGas.org website page *Processing Natural Gas*.
33. Oram, Brian. "Ammonia in Groundwater, Runoff, and Streams." *Water Research Center*, June 2014, [www.water-research.net/index.php/ammonia-in-groundwater-runoff-and-streams](http://www.water-research.net/index.php/ammonia-in-groundwater-runoff-and-streams).
34. "Penalties Associated with Violating U.S. Environmental Laws." *EnviroGuide*, Mar. 2013, [enviroguides.us/content/%E2%80%93penalties-associated-violating-us-environmental-laws](http://enviroguides.us/content/%E2%80%93penalties-associated-violating-us-environmental-laws).
35. Phillips, Jennifer. *Control and pollution prevention options for ammonia emissions*. No. PB-95-241790/XAB. VIGYAN, Inc., Vienna, VA (United States), 1995.
36. QMax Solutions. "Overview of H<sub>2</sub>S." *Tech Bulletin #13*.
37. Seider, Warren D., et al. *Product and Process Design Principles: Synthesis, Analysis, and Evaluation*. 4th ed., John Wiley & Sons Inc., 2017.
38. Shaver, Sally. "The Regulation of Ammonia Emissions in the United States." U.S. EPA, 18 July 2008.
39. "Sour Water Stripper Process." *Yokogawa America*, Yokogawa Electric Corporation, 2 Aug. 2016, [www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/](http://www.yokogawa.com/us/library/resources/application-notes/sour-water-stripper-process/).
40. South, Mia. "Approved Air Quality Implementation Plans." *EPA*, Environmental Protection Agency, 29 Sept. 2017, [www.epa.gov/air-quality-implementation-plans/approved-air-quality-implementation-plans](http://www.epa.gov/air-quality-implementation-plans/approved-air-quality-implementation-plans).
41. Stevens, D. K., and A. Mosher. "Fundamentals of Sour Water Stripping." *Brimstone Sulfur Symposia, Vail, Colorado*. 2008.
42. "Subchapter I. Plan Approval And Operating Permit Fees." *Pennsylvania Code*, [www.pacode.com/secure/data/025/chapter127/subchapItoC.html](http://www.pacode.com/secure/data/025/chapter127/subchapItoC.html).
43. "The Pennsylvania Code." *Permit Applications and Fees.*, [www.pacode.com/secure/data/025/chapter102/s102.6.html](http://www.pacode.com/secure/data/025/chapter102/s102.6.html).
44. Towler, Gavin, and Ray K. Sinnott. *Chemical engineering design: principles, practice and economics of plant and process design*. Elsevier, 2012.
45. "Usefulness of City as a Port Threatened by River Fumes." *The Philadelphia Record*, 14 Aug. 1944.
46. Vaquer-Sunyer, Raquel. "Ecosystem Impacts of Hypoxia: Thresholds of Hypoxia and Pathways to Recovery." *Research Gate*, 2011.
47. Wanek, Rick. "Monitoring H<sub>2</sub>S to Meet New Exposure Standards." *Occupational Health & Safety*, 1 Sept. 2011, [ohsonline.com/articles/2011/09/01/monitoring-h2s-to-meet-new-exposure-standards.aspx](http://ohsonline.com/articles/2011/09/01/monitoring-h2s-to-meet-new-exposure-standards.aspx).
48. Weiland, R.H., et al. "Stripping Phenolic Water." *Protreat.com*, 2013, [www.protreat.com/files/publications/85/S\\_344\\_sour\\_water\\_prf4.pdf](http://www.protreat.com/files/publications/85/S_344_sour_water_prf4.pdf).
49. "Who Has to Obtain a Title V Permit?" *EPA*, Environmental Protection Agency, 15 Mar. 2017, [www.epa.gov/title-v-operating-permits/who-has-obtain-title-v-permit](http://www.epa.gov/title-v-operating-permits/who-has-obtain-title-v-permit).
50. U.S. Energy Information Administration. "Fuel Consumed at Refineries." *East Coast (PADD 1) Fuel Consumed at Refineries*, U.S. Department of Energy, 21 June 2017, [www.eia.gov/dnav/pet/pet\\_pnp\\_capfuel\\_dcu\\_r10\\_a.htm](http://www.eia.gov/dnav/pet/pet_pnp_capfuel_dcu_r10_a.htm).

Section 28  
**Appendix**

## A.0: Project Description

### A.0.1: Project Description

#### 5. Alternate Technology for Sour Water Stripping

(recommended by P. C. Gopalratnam, Consultant – formerly DuPont, Invista) Background

Sour water is produced in many petrochemicals crude processing plants and refining operations in making petroleum products. It contains significant amounts of ammonium and sulfur compounds in concentrations exceeding thresholds of tolerance for water treatment and reuse. In other words, sour water typically cannot be directly discharged to waste treatment and it cannot be reused in other parts of the refinery unless treated. Process Description

Your task is to develop a strategy for sour water treatment that is potentially considered unconventional. Traditional technologies used to treat sour water involve some measure of air stripping. When air comes in contact with sour water, some of the ammonia and sulfur compounds will transfer to the air. This air is discharged assuming the exhaust to atmosphere is within permissible limits for the establishment. Should the permissible discharge be exceeded, fines will be incurred. Therefore, your task is to develop, and design an alternative to air stripping of sour water. Management at a facility in the state of Pennsylvania wishes to consider the use of natural gas as a substitute for air. Specifically, you are to develop a process for treating:

- 20-50 GPM sour water, containing 300-3000 ppm NH<sub>3</sub>, 5 ppm H<sub>2</sub>S and trace amounts of propane.
- Size the entire plant including upstream storage and downstream discharge or reuse to handle 75 kTons of sour water per year.

Note that there is a range of flow and composition, which will be addressed in a sensitivity analysis for any design that is submitted. It is assumed the natural gas stream containing the ammonia and sulfur compounds will be burned in some capacity. You will strip these components from the water, which can have a maximum of 20 ppm NH<sub>3</sub>.

Two options for the water (once the water is under 20 ppm NH<sub>3</sub>) are direct discharge as waste or further cleanup as BFW for steam generation. A final design should consider these two options and choose accordingly.

Detailed kinetics, thermodynamics, and key physical properties will be provided to the design group after project selection.

Your design submission must present the following:

- Information that will allow management a basic understanding of sour water treatment
- A description of a process using natural gas for sour water stripping, complete with a cost analysis of capital and operating expenses
- A description of a conventional design for traditional air stripping, which also requires an analysis of capital and operating expenses for comparison
- A description of the water treatment option to produce BFW, complete with capital and operating expense

Calculating the return on investment for this project also is a bit unconventional, as your economic analysis must consider the penalty associated with violating any air and water permit, the tradeoff between natural gas as a treatment option vs. selling the fuel, and a decision to treat the water. The PA state penalty for air and surface emissions may be found on the EPA website.

Specific Deliverables of this Design Project

1. Determine the best design for this system: a) determine the capital investment, and b) include and emphasize the appropriate use of design, corrosion considerations and safety features.

2. Consider the options of using Natural Gas in place of air in your design. Provide economic justifications for these alternatives. Remember the safety and environmental considerations associated with the use of Natural Gas.
3. Include details for all gas emission (NH<sub>3</sub>, NO<sub>x</sub>, SO<sub>x</sub>, etc.) to the environment as well as in liquid waste discharge to the river and calculate the penalty for such discharge exceeding the limits.
4. Include storage considerations for process and other raw materials as well as the final product with technical specifications.
5. Determine if there is any impact on plant capacity as a function of sour water composition and pH.
6. Conduct and document a safety review that contains two parts: a) Hazards: a clear description of the major hazards of this process and what design features are incorporated to circumvent these hazards, and b) Inherent Safety highlights of one or more of the following inherent safety concepts: i) design features for easier and effective maintainability, and ii) design features using inherent safety concepts that circumvent accidents even when instruments fail or operators make mistakes.
7. Develop recommendations for the best design and state your reasons for these recommendations.
8. Provide a list of all equipment used in the process, including type, description, function, materials of construction to minimize corrosion, size, operating conditions, purchase and installed costs, and all important specifications.

#### Appendices

1. A1 A detailed investment analysis appears in the body of your design report. This appendix includes spreadsheet calculations showing formulas, sample calculations, and sources of the methods used.
2. A2 Safety Review- Enclose the MSDSs to this Appendix.
3. A3 Computer Process Simulators and Other Programs - Use generally available process simulators (ASPEN PLUS®, etc.) together with spreadsheets and student-developed computer programs. Include a description of when and where each simulation package was used, and the important input and output sheets. Relate this information (using the appropriate labels) to the PFD or the P&ID.
4. A4 Back-up/Support Data and Calculations - Provide documentation for the calculations made by hand at least on a sample basis, but preferably include all hand calculations made for the design. Include flow charts where possible. All special-purpose computer programs must be documented by including a brief description, input, and output files. This means that cell formulas must be included for your spreadsheet calculations.

#### References

- Seider, W. D., et al.; *Product and Process Design Principles: Synthesis, Analysis and Evaluation*, 4th Edition
- D. K. Stevens and A. Mosher, "Fundamentals of Sour Water Stripping," in *Brimstone Sulfur Symposia*, Vail, Colorado, 2008.
- T. Armstrong, B. Scott, K. Taylor and A. Gardner, "Sour Water Stripping," *Today's Refinery*, 1996.
- K. W. Won, "Sour Water Stripper Efficiency," *Plant/Operations Progress*, vol. 2, no. 2, pp. 108113, 1983.
- T. J. Edwards, G. Maurer and J. M. Prausnitz, "Vapor-Liquid Equilibria in Multi-component Aqueous Solutions of Volatile Weak Electrolytes," *AIChE Journal*, vol. 24, no. 6, pp. 966-976, 1978.
- S. Al-Dhafiri and L. Reddy, "Erosion - Corrosion of SS316L Trays in FCC's Sour Water Stripper – A Case Study," in *NACE Corrosion 2010 Conference and Expo*, 2010.

- US EPA, "Profile of the Oil and gas Extraction Industry," Office of Enforcement and Compliance Assurance, Washington, D.C., 2000.
- Pennsylvania DEP at [www.dep.pa.gov/](http://www.dep.pa.gov/) or Pennsylvania DEP, "Draft Oil Brine Characteristics Report," Pennsylvania Department of Environmental Protection, 1999 or <http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-90878/263-4180-001.pdf>

## A.0.2: Additional Details

### Some helpful hints:

The production of sour water, which contains compounds of ammonium and sulfur in substantial amounts, is observed in many petrochemical processes as a result of refining. In most cases, these sulfur and ammonium compounds are present in concentrations that are too high for discharge to a water treatment plant or for reuse as process water within the refinery. To remove these compounds and allow for the disposal or reuse of sour water, refineries commonly employ a stripping process in which a vapor stream is contacted with the sour water so that the undesired ammonium and sulfur compounds are transferred to the vapor phase. The purpose of this project was to **develop a stripping process** as that makes use of natural gas as a stripping medium, and to then compare the technical and economic feasibility of that process to more traditional air stripping methods.

In accordance with the problem statement, the designed process must be able to handle sour water flow rates to meet the annual production rate and ammonia exit concentration as specified. Any deviations in discharge amounts from specifications must be used to calculate the penalty or fines assessed by the State of PA.

The relatively simple traditional stripping methods are complicated by the equilibrium reactions of ammonia and hydrogen sulfide within the sour water, provided in Table 1, and the **water chemistry** of the system can greatly impact the extent of the removal of ammonium and sulfur compounds.

With these reactions occurring the pH also plays a role in determining how much ammonia and hydrogen sulfide can be stripped, and it was found that the ideal stripping pH for hydrogen sulfide removal is substantially lower than that of ammonia. Hydrogen sulfide is most easily stripped at a pH below 5 in order to maximize the protonation of sulfide ions, while ammonia stripping is most efficient at a pH above 10 as the formation of ammonium ions is reduced. Due to these considerations, it is necessary that any modeling method used in simulating the stripping must take water chemistry into account, and the pH of the sour water being fed to the process was monitored to ensure that it is basic enough to maximize the removal of ammonia in accordance with the problem statement.

With regards to the use of natural gas as a sour water stripping medium, there is relatively little information available in the literature. However, using natural gas as the vapor in a sour water stripping column has the potential to be attractive from an energy and environmental standpoint, as the natural gas exiting the absorption column can be burned to recover heat for process use while simultaneously combusting the hazardous ammonia and hydrogen sulfide compounds.

Based upon the problem statement develop two similar designs, one that uses natural gas as a stripping medium and another more traditional design in which air would be used. This would allow for a direct comparison of the feasibility and economic attractiveness of the two processes.

Table 1: Chemical Equilibrium Reactions

$2H_2O \leftrightarrow H_3O^+ + OH^-$	(1)
$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$	(2)
$H_2O + H_2S \leftrightarrow H_3O^+ + HS^-$	(3)
$H_2O + HS^- \leftrightarrow H_3O^+ + S^{2-}$	(4)

**A.0.3: Project Author Amendment to Standard Incoming Flow Rates**

Team 5 & others,

The range of sour water feed for this project is suggested for extreme operating conditions and it is suggested one would see this range over a typical year. Let us assume that the actual variation during regular operation to be between 30 gpm and 50 rpm only. The lower end of the range at 20 gpm would correspond to a couple of days of transience before and after the annual shutdown of the plant.

As Prof. Fabiano suggested, design the column for a routine operation of 30 to 50 gpm range with a turndown of 60%. Then consider placing the column on total recycle (usually called the stand-by mode) during transitions (2 days each) around the annual shutdown.

I hope this helps.

Gopal.



## A.1: Calculations

### A.1.1: Calculation of amount of natural gas used by stripping process vs amount consumed by average east coast refinery

- Amount of Natural Gas Used in the Natural Gas Stripping Process

$$\left( \left( 178,623 \frac{CF}{hr} \right) * \left( 8000 \frac{hr}{yr * refinery} \right) = 1,428,984,000 \frac{CFY}{refinery} (@ 180^{\circ}F; 640^{\circ}R) \right)$$

$$\left( \frac{T_1}{V_1} = \frac{T_2}{V_2} \right)$$

$$\left( 1,428,984,000 \frac{CFY}{refinery} (@ 180^{\circ}F; 640^{\circ}R) = 1,161,049,500 \frac{SCFY}{refinery} (@ 60^{\circ}F; 520^{\circ}R) \right)$$

- Average Amount of Natural Gas Consumed by an East Coast Refinery

$$\left( \left( 52,323 \frac{MSCFY^3}{E. C. refinery} \right) * \left( \frac{1 ref.}{9 ref.} \right) * 1,000,000 \frac{1}{M} = 5,813,366,667 \frac{SCFY}{refinery} (@ 60^{\circ}F; 520^{\circ}R) \right)$$

### A.1.2: Calculations for intermediate temperature of air and natural gas before adding steam

- Average flow rates, 10 mole% water vapor, column inlet temperature of 190
- Air Formula

$$T_m = \left( \frac{T_{air,i} + \left( Flow_{air} * C_{p,air} * (T_{column} - T_{air,i}) - MassFrac_{H2O} * Flow_{air} * C_{p,H2O} * (T_{H2O} - T_{column}) \right)}{C_{p,air} * Flow_{air}} \right)$$

- Air Average Flow Rate Example

$$171 = \left( \frac{70 + \left( 23,992 * 0.17 * (190 - 70) - 0.065 * 23,992 * 0.45 * (300 - 190) \right)}{0.17 * 23,992} \right)$$

- Natural Gas Formula

$$T_m = \left( \frac{T_{gas,i} + \left( Flow_{gas} * C_{p,gas} * (T_{column} - T_{gas,i}) - MassFrac_{H2O} * Flow_{gas} * C_{p,H2O} * (T_{H2O} - T_{column}) \right)}{C_{p,gas} * Flow_{gas}} \right)$$

- Natural Gas Average Flow Rate Example

$$180 = \left( \frac{42 + \left( 14,664 * 0.533 * (190 - 42) - \frac{1}{9} * 14,664 * 0.45 * (300 - 190) \right)}{0.533 * 14,644} \right)$$

### A.1.3: Average Yearly Flow Rate

$$\left( 37.5 \text{ GPM} = 37.5 \frac{\text{gal}}{\text{min}} = \frac{\left( 75,000 \frac{\text{ton}}{\text{yr}} \right) * \left( 2000 \frac{\text{lb}}{\text{ton}} \right)}{\left( 8000 \frac{\text{hr}}{\text{yr}} \right) * \left( 60 \frac{\text{min}}{\text{hr}} \right) * \left( 8.309 \frac{\text{lb}}{\text{gal}} \right)} \right)$$

### A.1.4: Amount of Ammonia Removed from Sour Water Annually

$$\left( \left( 29.8 \frac{\text{lb}}{\text{hr}} \right) * \left( 8000 \frac{\text{hr}}{\text{yr}} \right) * \left( \frac{1 \text{ ton}}{2000 \text{ lb}} \right) * \left( \frac{\$500}{\text{ton}} \right) = \$59,600 \right)$$

### A.1.5: Sensitivity Analysis for Sulfuric Acid Addition (Air and Natural Gas)

- Sulfuric Acid Sensitivity Analysis for Air Stripping. The bolded blue numbers represent the flow rate of air required to strip the sour water feed to 20 ppm of ammonia and 0.1 ppm of hydrogen sulfide with 0.6 lb/hr of sulfuric acid. The ASPEN simulations were run using 5 ideal trays, which is why the numbers do not match the control equation.

Ammonia Conc.	Sour Water Feed Flow	
	15,000 lb/hr (30 gpm)	25,000 lb/hr (50 gpm)
300 ppm	<b>17,248 lb/hr</b>	<b>20,738 lb/hr</b>
3000 ppm	<b>31,631 lb/hr</b>	<b>39,970 lb/hr</b>

- Sulfuric Acid Sensitivity Analysis for Natural Gas Stripping. The bolded blue numbers represent the flow rate of natural gas required to strip the sour water feed to 20 ppm of ammonia and 0.1 ppm of hydrogen sulfide with 0.55 lb/hr of sulfuric acid. The ASPEN simulations were run using 5 ideal trays, which is why the numbers do not match the control equation.

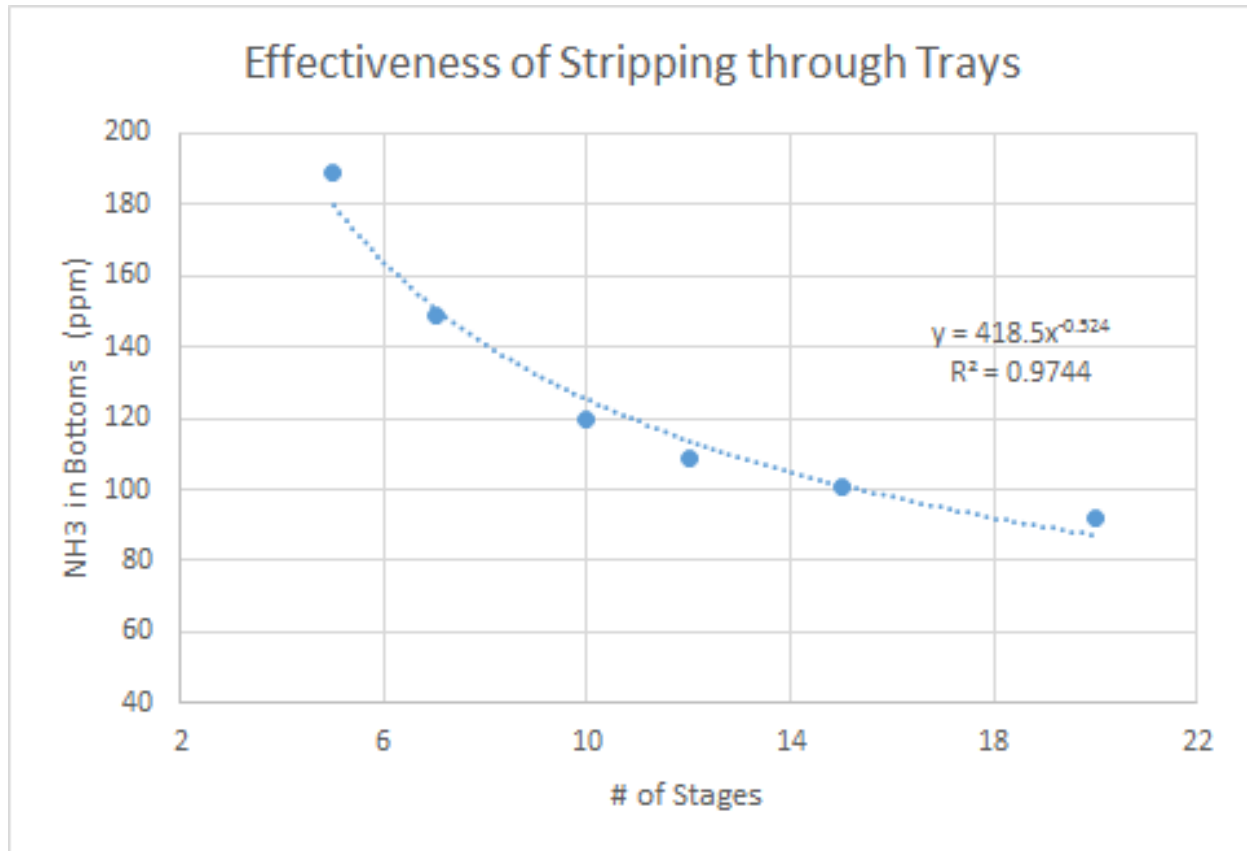
Ammonia Conc.	Sour Water Feed Flow	
	15,000 lb/hr (30 gpm)	25,000 lb/hr (50 gpm)
300 ppm	<b>11,454 lb/hr</b>	<b>13,963 lb/hr</b>
3000 ppm	<b>23,930 lb/hr</b>	<b>30,632 lb/hr</b>

## A.2: Figures

### A.2.1: Effect of Various Parameters on Stripping Efficacy

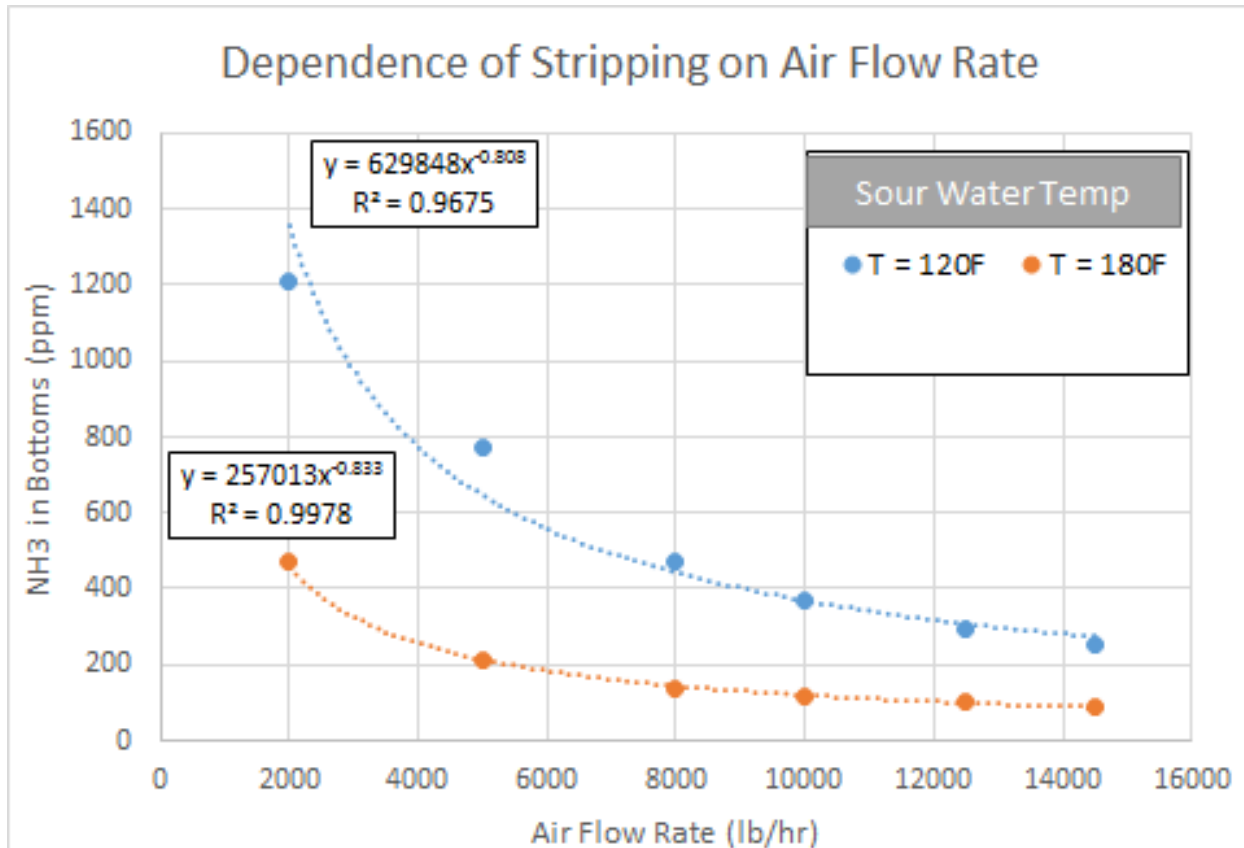
#### A.2.1.1: Effect of Number of Stages on Stripping Efficacy

- An early test of an integral variable of the process, number of trays, and how the extent of stripping is affected by changing it. Increasing the number of trays increases the amount of ammonia that is stripped by a constant air flow rate.



**A.2.1.2: Effect of Air Flow Rate and Water Temperature on Stripping Efficacy**

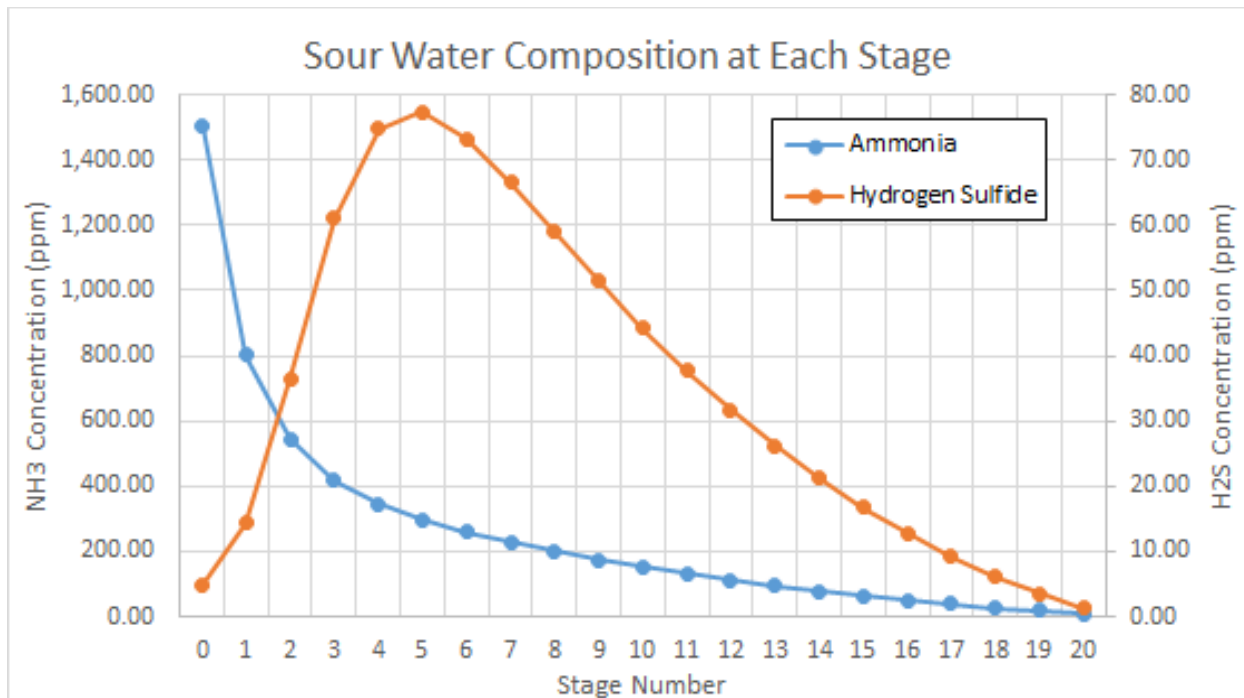
- This graph shows the results of an early test to determine how water temperature and stripping agent air flow rate affects the extent of stripping. Increasing both the sour water temperature and air flow rate has a positive effect on the amount of ammonia that can be stripped.



## A.2.2: Column Tray Profiles

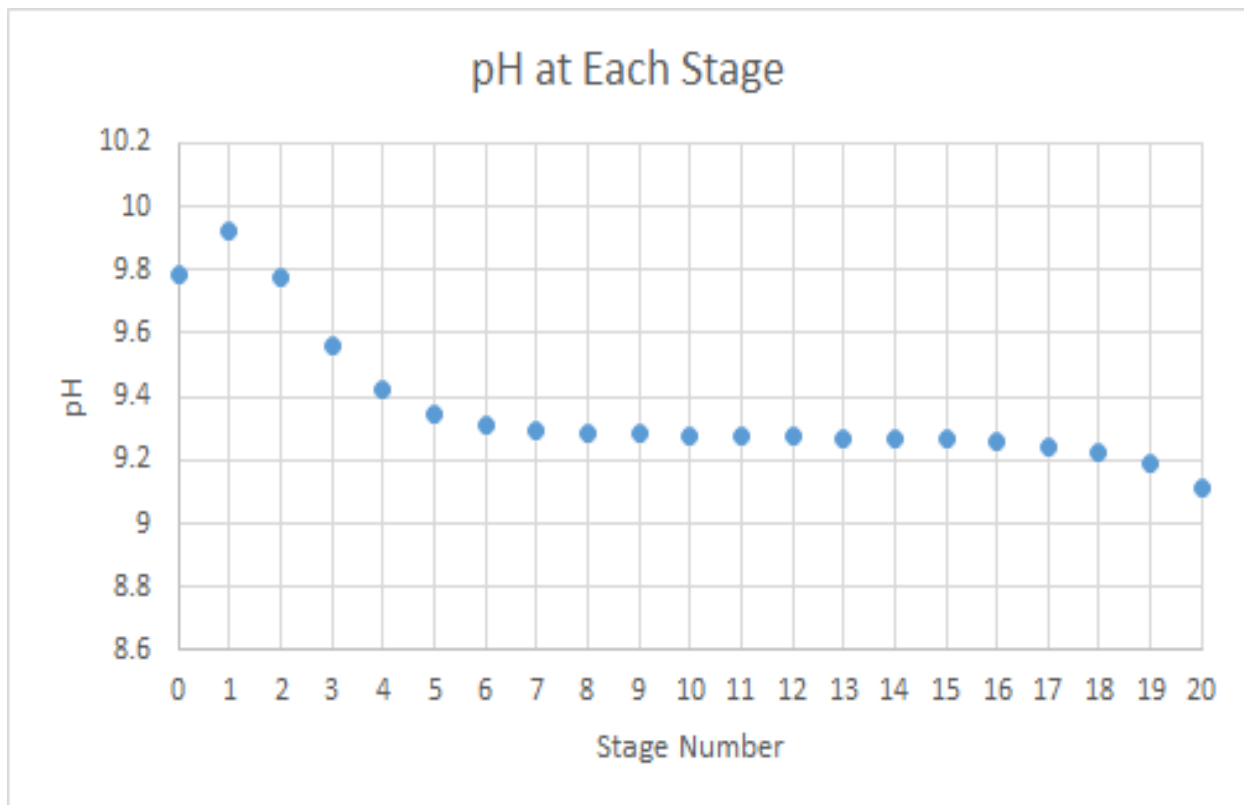
### A.2.2.1: Column Internal Hydrogen Sulfide and Ammonia Concentration Profiles

- This is an example of an ASPEN simulation where the concentrations of the contaminants were measured on each tray. This concentration is only for the dissolved gas, not including its dissociated constituents.



### A.2.2.2: Column Internal pH Profiles

- This is an example of an ASPEN simulation where the pH of the sour water was measured on each tray.



### A.2.3: Control Equation Formulation

- This excerpt from spreadsheet calculation spreadsheet shows the control equations from Section 23.2 being optimized for different sour water conditions. The equation was formulated to calculate more than enough stripping agent to strip the sour water when at the minimum and maximum ammonia concentrations and the minimum and maximum flow rates.

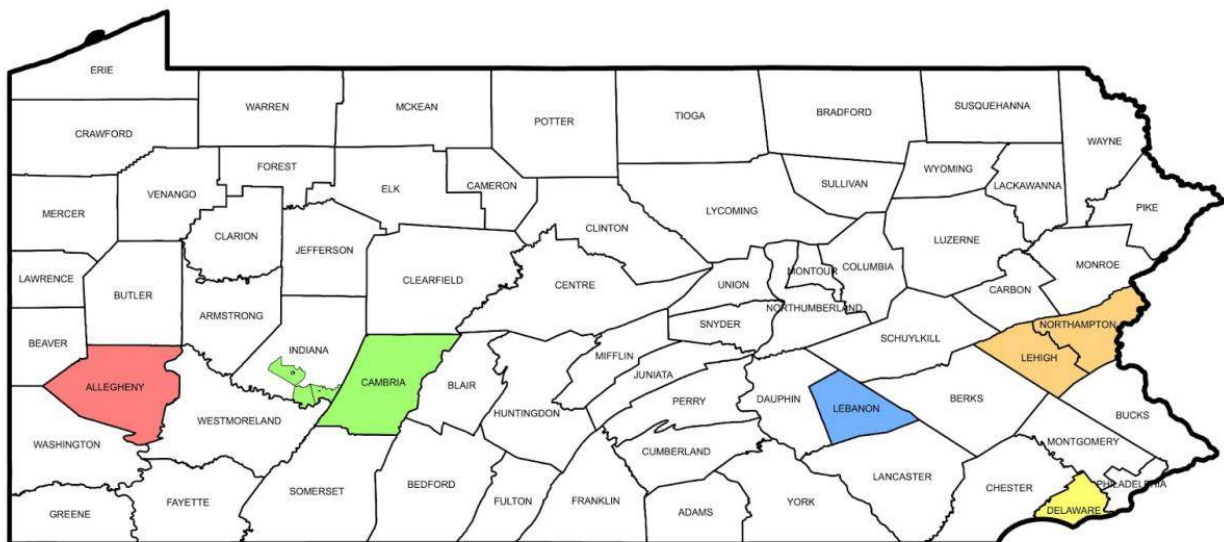
Control Equation Formulation for Required Stripping Agent; Adapted for Acid Addition											
Air Stripping Process					Natural Gas Stripping Process						
NH3 ppm	sour water GPM	sour water lb/hr	air lb/hr (ASPEN)	air lb/hr (eqn)	% overshoot	NH3 ppm	sour water GPM	sour water lb/hr	CH4 lb/hr (eqn)	% overshoot	
300	30	14956.8	18028.58845	18186.23781	0.87%	300	30	14956.8	11342.64218	11682.9325	3.00%
1650	30	14956.8	23911.20105	24577.20062	2.79%	1650	30	14956.8	15472.46895	15555.8835	0.54%
3000	30	14956.8	26463.08092	26979.30746	1.95%	3000	30	14956.8	16940.87755	17096.73625	0.92%
300	40	19942.4	18518.70217	18955.17561	2.36%	300	40	19942.4	12041.43965	12042.72021	0.01%
1650	40	19942.4	25572.34426	26400.62639	3.24%	1650	40	19942.4	16823.79553	17111.28154	1.71%
3000	40	19942.4	28196.66387	28637.37195	1.56%	3000	40	19942.4	18597.87353	19188.22811	3.17%
300	50	24928	20943.77678	21609.7688	3.18%	300	50	24928	13815.36184	14051.4494	1.71%
1650	50	24928	30103.36991	30114.14234	0.04%	1650	50	24928	19726.19605	20199.97906	2.40%
3000	50	24928	33186.97288	34019.63854	2.51%	3000	50	24928	21685.7145	22347.81058	3.05%
Air: Mean Flow and Concentration					Natural Gas: Mean Flow and Concentration						
1650	37.5	18696		25656.74676		1650	37.5	18696	16470.93374		



### A.2.4: Pennsylvania PM<sub>2.5</sub> Nonattainment Areas

- The map below represents the nonattainment areas in Pennsylvania for particulate matter of size less than 2.5 microns. Nonattainment areas are areas where the ambient air in that area is of worse quality than the NAAQS standards.

**Pennsylvania PM<sub>2.5</sub> Nonattainment Areas**  
Areas are Shaded Based on EPA's December 18, 2014 Designations



**PM<sub>2.5</sub> Nonattainment Areas**



### A.3: Permits

#### A.3.1: Warren Refinery Permit (excerpt)



**COMMONWEALTH OF PENNSYLVANIA  
DEPARTMENT OF ENVIRONMENTAL PROTECTION  
AIR QUALITY PROGRAM**

**TITLE V/STATE OPERATING PERMIT**

Issue Date:	December 14, 2012	Effective Date:	July 9, 2015
Revision Date:	July 9, 2015	Expiration Date:	November 30, 2017
Revision Type:	Amendment		

In accordance with the provisions of the Air Pollution Control Act, the Act of January 8, 1960, P.L. 2119, as amended, and 25 Pa. Code Chapter 127, the Owner, [and Operator if noted] (hereinafter referred to as permittee) identified below is authorized by the Department of Environmental Protection (Department) to operate the air emission source(s) more fully described in this permit. This Facility is subject to all terms and conditions specified in this permit. Nothing in this permit relieves the permittee from its obligations to comply with all applicable Federal, State and Local laws and regulations.

The regulatory or statutory authority for each permit condition is set forth in brackets. All terms and conditions in this permit are federally enforceable applicable requirements unless otherwise designated as "State-Only" or "non-applicable" requirements.

**TITLE V Permit No: 62-00017**

Federal Tax Id - Plant Code: 25-1411751-1

<b>Owner Information</b>
Name: UNITED REFINING CO OF PA Mailing Address: PO BOX 780 WARREN, PA 16365-0780
<b>Plant Information</b>
Plant: UNITED REFINING CO/WARREN PLT Location: 62 Warren County 62001 Warren City SIC Code: 2911 Manufacturing - Petroleum Refining
<b>Responsible Official</b>
Name: TIM RUTH Title: ENVIRONMENTAL COMPLIANCE Phone: (814) 726 - 4609
<b>Permit Contact Person</b>
Name: WILLIAM J ROY Title: ENVIRONMENTAL ENGINEER Phone: (814) 726 - 4859
[Signature] _____ EDWARD F. ORRIS, P.E., NORTHWEST REGION AIR PROGRAM MANAGER

### A.3.2: Marcus Hook Refinery Permit (excerpts)

 23-00001	SUNOCO INC (R&M)/MARCUS HOOK REFINERY	
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**COMMONWEALTH OF PENNSYLVANIA  
DEPARTMENT OF ENVIRONMENTAL PROTECTION  
AIR QUALITY PROGRAM**

**TITLE V/STATE OPERATING PERMIT**

Issue Date: November 18, 2008	Effective Date: August 7, 2012
Revision Date: August 7, 2012	Expiration Date: November 18, 2013
Revision Type: Amendment	

In accordance with the provisions of the Air Pollution Control Act, the Act of January 8, 1960, P.L. 2119, as amended, and 25 Pa. Code Chapter 127, the Owner, [and Operator if noted] (hereinafter referred to as permittee) identified below is authorized by the Department of Environmental Protection (Department) to operate the air emission source(s) more fully described in this permit. This Facility is subject to all terms and conditions specified in this permit. Nothing in this permit relieves the permittee from its obligations to comply with all applicable Federal, State and Local laws and regulations.

The regulatory or statutory authority for each permit condition is set forth in brackets. All terms and conditions in this permit are federally enforceable applicable requirements unless otherwise designated as "State-Only" or "non-applicable" requirements.

**TITLE V Permit No: 23-00001**

Federal Tax Id - Plant Code: 23-1743283-12

<u>Owner Information</u>
Name: SUNOCO INC Mailing Address: PO BOX 426 MARCUS HOOK, PA 19061-0426
<u>Plant Information</u>
Plant: SUNOCO INC (R&M)/MARCUS HOOK REFINERY Location: 23 Delaware County 23825 Marcus Hook Borough SIC Code: 2911 Manufacturing - Petroleum Refining
<u>Responsible Official</u>
Name: PAUL BRAUN Title: ENV ENGR Phone: (610) 859 - 3392
<u>Permit Contact Person</u>
Name: PAUL BRAUN Title: ENV ENGR Phone: (610) 859 - 3392
[Signature] _____ JAMES D. REBARCHAK, SOUTHEAST REGION AIR PROGRAM MANAGER



23-00001

SUNOCO INC (R&M)/MARCUS HOOK REFINERY



**SECTION D. Source Level Requirements**

**Operating permit terms and conditions.**

[Additional authority for this permit condition is also derived from 40 CFR §§ 60.102 and 104.]

Emissions from the FCCU catalyst regenerator shall not exceed either of the following:

- (a) SO<sub>2</sub> - 9.8 lbs of SO<sub>2</sub> per 1000 lbs of coke burn-off in the catalyst regenerator determined daily on a 7-day rolling average basis; and
- (b) PM - 1.0 lbs of PM per 1000 lbs of coke burn-off in the catalyst regenerator. The particulate matter shall be measured at the main stack of the FCCU.

[Compliance with the above assures compliance with 40 CFR § 63.1564(a)(1).]

**# 006 [25 Pa. Code §127.441]**

**Operating permit terms and conditions.**

[Additional authority for this permit condition is also derived from 40 CFR § 60.103.]

CO emissions from the FCCU shall not exceed 500 ppmvd on a one-hour average basis (at 0% oxygen), and 2851.7 tons in any 12 consecutive month period.

The 500 ppmvd CO limit above does not apply during periods of planned maintenance that has been pre-approved by PADEP according to the requirements of 40 CFR § 63.1576(j).

[Compliance with this condition assures compliance with 40 CFR § 63.1565(a)(1) and 40 CFR § 60.105(e).]

**# 007 [25 Pa. Code §127.441]**

**Operating permit terms and conditions.**

SO<sub>2</sub> emissions from the FCCU shall not exceed 500 ppmvd.

[Compliance with this condition assures compliance with 25 Pa. Code 123.21.]

**# 008 [25 Pa. Code §127.441]**

**Operating permit terms and conditions.**

Ammonia emissions shall not exceed:

- (a) 8.5 lbs/hr (averaged monthly); and
- (b) 37.3 tons in any 12 consecutive month period.

**# 009 [25 Pa. Code §127.441]**

**Operating permit terms and conditions.**

Ammonia slip shall not exceed 10 ppmvd, corrected to 0% oxygen.

**Fuel Restriction(s).**

**# 010 [25 Pa. Code §127.441]**

**Operating permit terms and conditions.**

No. 3 CO Boiler (COB3) shall only combust refinery fuel gas (RFG) and/or natural gas as the auxiliary fuel.

**Throughput Restriction(s).**

**# 011 [25 Pa. Code §127.441]**

**Operating permit terms and conditions.**

No exhaust from the 10-4 Plant Sour Water Stripper Overhead shall be combusted in the No. 3 CO Boiler (COB3).

## A.4: Quotations and Equipment Specifications

### A.4.1: pH Meter Quotation (pH Converter) (excerpt)

#### General Specifications

Model PH450G  
pH and Redox (ORP) Converter



GS 12B07C05-01E

The EXAxt 450 series is designed to combine the superior functionality of the Yokogawa EXA series with the ease of use offered in pocket computers (PDA).

The PH450 offers the best accuracy in the industry by combining the pH measurement with advanced temperature compensation functionality, preloaded calibration standards and stability checks.

The PH450 is a true multivariable analyzer that combines pH with Temperature and ORP (Redox) measurement and all these measurements can be utilised through the different output functions: two mA current outputs, four independent SPDT contact outputs and HART®. Both DD and DTM files are available for direct connection to HART® Handheld terminal, HMI monitor and Pactware PC configurator.

The PH450 offers full functionality with PID control on either mA output(s) or on contact output(s) and with integral wash function.

Most important requirements for Electrochemical Analyzers are reliability and repeatability. This is guaranteed in PH450 sensor diagnostics impedance monitoring of both pH and reference cell. In addition to this a dynamic sensor checking coupled with the wash cycle function assure trouble free and accurate analysis with a minimum of maintenance.

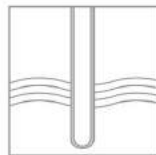
Truly unique is the EXAxt450 series in the Human Machine Interface. The high resolution graphical display and the touchscreen operation make all information visible to the operator. Configuration with the touchscreen is as easy as operating a PDA. Simply choose the language of choice and on screen instructions assure that the best configuration for the application is obtained.



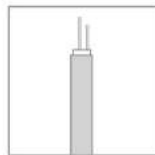
#### Features

- Easy touchscreen operation
- IP66/NEMA 4X 1/2DIN enclosure for field mounting and panel mounting
- Unique HMI menu structure in 8 languages
- Predefined buffer solutions
- Trending display up to 2 weeks
- On-screen logbooks store calibration data, configuration changes and events
- Advanced Process Temperature Compensation
- Three sets of preloaded pH buffer standards

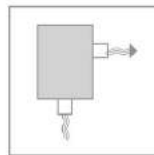
#### System Configuration



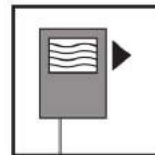
Sensors



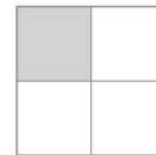
Cables



Fittings



Transmitters



Accessories

**YOKOGAWA** ◆  
Yokogawa Electric Corporation

Yokogawa Electric Corporation  
2-9-32, Nakacho, Musashino-shi, Tokyo, 180-8750 Japan  
Tel.: 81-422-52-5617 Fax.: 81-422-52-6792

GS 12B07C05-01E  
©Copyright Jul. 2007  
1st Edition Jul.02,2007  
2nd Edition Mar.27,2008

**General Specifications of EXAxt PH450**

**A) Input specifications:** Dual high impedance input ( $\geq 10^{12}\Omega$ ).

**B) Input ranges**

pH	: -2 to 16 pH.
ORP	: -1500 to 1500 mV.
rH	: 0 to 100 rH.
Temperature	
- Pt1000	: -30 to 140°C.
- Pt100	: -30 to 140°C.
- 350Ω (DKK)	: -30 to 140°C.
- 5k1	: -30 to 140°C.
- 6k8	: -30 to 140°C.
- PTC10k	: -30 to 140°C.
- NTC 8k55	: -10 to 120°C.
- 3kBalco	: -30 to 140°C.

**C) Accuracy**

pH input	: $\leq 0.01$ pH.
ORP input	: $\leq 1$ mV.
Temperature	: $\leq 0.3^\circ\text{C}$ ( $\leq 0.4^\circ\text{C}$ for Pt100)
Step response	: $< 4$ sec for 90% (pH 7 - pH 4).

Note on performance specifications

The following tolerance is added to above performance.

mA output tolerance:  $\pm 0.02$  mA of "4-20 mA"

**D) Transmission signals**

General	: Two isolated outputs of 4-20 mA. DC with common negative. Maximum load 600Ω. Bi-directional HART® digital communication, superimposed on mA1 (4-20mA) signal.
Output function	: Linear or Non-linear (21-step table) output for pH, temperature, ORP or rH.
Control function	: PID control.
Burn out function	: Burn up (21.0 mA) or burn down (3.6 mA) to signal failure acc. NAMUR NE43.
Hold	: Adjustable damping. Expire time : The mA-outputs are frozen to the last/fixed value during calibration/commissioning.

**E) Contact outputs**

General	: Four SPDT relay contacts with display indicators.
Switch capacity	: Maximum values 100 VA, 250 VAC, 5 Amps. (*) Maximum values 50 Watts, 250 VDC, 5 Amps. (*)
Status	: High/Low process alarms, selected from pH, ORP, rH and temperature. Configurable delay time and hysteresis. Failure annunciation.
Control function	: On/Off, PID duty cycle or pulsed frequency control.
Wash	: Contact can be used to start manual- or interval time wash cycles.
Hold	: Contact can be used to signal the Hold situation.
Fail	: Contact S4 is programmed as fail-safe contact.

(\*)Note: When contact output current is more than 4 Amps, ambient temperature should be less than 40 °C.

**F) Contact input** : Remote wash cycle start.

**G) Temperature compensation**

**Function** : Automatic or manual. Compensation to Nernst equation. Process compensation by configurable temperature coefficient, NEN6411 for water or strong acids/bases or programmable matrix.

**H) Calibration** : Semi-automatic 1 or 2 point calibration using pre-configured NIST, US, DIN buffer tables 4, 7 & 9, or with user defined buffer tables, with automatic stability check. Manual adjustment to grab sample.

**I) Logbook** : Software record of important events and diagnostic data readily available in the display or through HART®.

**J) Display** : Graphical Quarter VGA (320 x 240 pixels) LCD with LED backlight and touchscreen. Plain language messages in English, German, French, Spanish, Italian, Swedish, Portuguese and Japanese.

**K) Shipping details**

**Package size** : 290 x 300 x 290 mm (L x W x D) (11.5 x 11.8 x 11.5 inch).

**Package weight**: app. 2.5 kg (5.5 lbs).

**Converter weight**: app. 1.5 kg

**L) Housing**

: Cast Aluminium housing with chemically resistant coating; Polycarbonate cover with Polycarbonate flexible window  
: Protection IP66 / NEMA 4X / CSA Type 3S

**Colour** : Silver grey

PH450G-A(D)-A: IP66 cable glands are supplied with the unit

PH450G-A(D)-U: NEMA 4X close up plugs are mounted in the unused cable entry holes and can be replaced by conduit fittings as required  
Pipe, Panel or Wall mounting using optional hardware

**M) Power supply**

PH450G-A :Ratings; 100-240 V AC Acceptable range; 90 to 264 V AC  
Ratings; 50/60 Hz Acceptable range; 50 Hz  $\pm 5\%$ , 60 Hz  $\pm 5\%$   
Power Consumption; 15 VA

PH450G-D :Ratings; 12-24 V DC Acceptable range; 10.8 to 26.4 V DC  
Power Consumption; 10 W

**N) Safety and EMC conforming standards**

**Safety** :EN 61010-1  
CSA C22.2 No.61010-1  
UL 61010-1  
FM3611 Class I, Div.2, Group ABCD,T6 for Ta -20 to 55°C

**EMC** :conforms to EN61326 Class A, AS/NZS CIPR 11

Installation altitude: 2000 m or less  
Category based on IEC 61010: II (Note)

## A.4.2: Acid Storage Tank

4/16/2018

Product Print



INDCO, Inc.  
Your direct source for superior mixing equipment  
4040 Earnings Way New Albany IN 47150  
Telephone: (800) 942 4383 • Fax: (812) 944 9742  
info@indco.com • www.indco.com  
HOME > SHOP > VIEW PRODUCT

### PET10-0200 200-Gallon Flat Bottom Polyethylene Tank

**\$616.00**



#### Features

This 200-gallon high-density polyethylene flat-bottom cylindrical tank is a cost effective universal mixing vessel. Single piece rotationally molded, FDA approved and highly chemical resistant, HDPE tanks are ideal for a broad range of applications from chemical processing to food production. They are a particularly good choice for use with acids and caustics. Each model features a stepped flange around the open top to contain drips, translucent sides for visual liquid level observation and a loose-fitting cover. Many tank fittings, spigots and drains are available and can be factory for field installed. Please call for a quote on these items. Steel tank stands and tank stands with mixer mounting brackets are sold separately.

#### Specifications

##### Impeller

##### Tank/Liner/Drum Specifications

Capacity	200 Gallons
Depth	48"
Diameter	36" OD
Maximum Temperature	140° F
Wall	5/16"

#### Related Products



200-Gallon Flat Bottom Polyethylene Tank Stand



200-Gallon Flat Bottom Polyethylene Tank Stand w/ Mixer Bracket

### A.4.3: Acid Mixing Tank

4/16/2018

Product Print



INDCO, Inc.  
Your direct source for superior mixing equipment  
4040 Earnings Way New Albany IN 47150  
Telephone: (800) 942 4383 • Fax: (812) 944 9742  
info@indco.com • www.indco.com  
HOME > SHOP > VIEW PRODUCT

#### SST-400 400-Gallon Stainless Steel Mixing Tank

\$9220.25



#### Features

Our versatile and ruggedly-constructed 304 stainless steel tanks are fabricated by expert welders with top quality workmanship. This 400-gallon base model has a 52" inside diameter, 46-1/2" straight side, sloped bottom with 1" NPT drain and stands on four legs. Our general mixing tank design also features an open top with flanged lip for added strength. A 2B Mill finish inside and out with interior welds ground flush and brushed exterior welds is our standard industrial finish. Our sanitary deluxe finish option is a 120-grit #4 finish with all interior welds ground flush and polished. Exterior welds are ground and buffed smooth. All welds are passivated and leak tested. All of our tanks can also be quoted in 316 stainless steel. A multitude of customizable features are available including mixer mounting brackets, heating or cooling jackets, surface finishes to 15Ra, electropolishing, drain valves, casters and lids. Please call us for the most up to date stainless steel pricing and the industry's best possible lead times.

Need help selecting the ideal tank and features for your process? Talk to one of our friendly engineers! We can model agitation for various mixer and tank combinations with your product properties for optimized results. Pharmaceutical grade sealed sanitary mixing vessels are also available. See our sanitary mixing products or call us for a quote.

#### Specifications

##### Impeller

#### Related Products



##### Stainless Steel Tank Lid



1-1/2 HP Air Gear Drive Heavy Duty Clamp Mount Mixer



1 HP Electric Gear Drive Heavy Duty Clamp Mount Mixer



### A.4.4: Polyethylene Chemical Resistance Chart (excerpt)

# CDF Technical Memo

Number 1

July 2004

## Polyethylene Chemical Resistance Chart

CDF Corporation uses only the highest quality raw materials available. These raw materials have outstanding resistance to both physical and chemical attack. The following chart should be used as a guide for evaluating the suitability of our products with the chemical agent you plan to use. Special consideration must be given to the expected service temperature, stress involved in the application, as well as the length and type of exposure (i.e. intermittent or continuous).

CODES	REAGENT	CONC.	LDPE		HDPE	
			70°	140°	70°	140°
A	Resistant no indication that serviceability would be impaired.					
B	Variable resistance, depending on conditions of use.					
C	Unresistant, not recommended for service applications under any conditions.					
-	Information not available.					
	<b># Plasticizer.</b>					
	Certain types of chemicals are absorbed to varying degrees by polyethylene causing swelling, weight-gain, softening and some loss of yield strength. These plasticizing materials cause no actual chemical degradation of the resin. Several of these chemicals have a strong plasticizing effect (e.g. aromatic hydrocarbons benzene), whereas others have weaker effects (e.g. gasoline). Certain plasticizers are sufficiently volatile that if they are removed from contact with the polyethylene, the part will "dry" out and return to its original condition with no loss of properties.					
	<b>+ Oxidizers.</b>					
	Oxidizers are the only group of materials capable of chemically degrading polyethylene. The effects on the polyethylene may be gradual even for strong oxidizers and short-term effects may not be measurable. However, if continuous long-term exposure is intended, the chemical effects should be checked regularly.					
	Acetone		B	C	B	C
	Acetaldehyde*	100%	B	C	B	C
	Acetic Acid*	10%	A	A	A	A
	Acetic Acid*	60%	A	B	A	B
	Acetic Anhydride*		C	C	C	C
	Air		A	A	A	A
	Aluminum Chloride	all conc	A	A	A	A
	Aluminum Fluoride	all conc	A	A	A	A
	Aluminum Sulphate	all conc	A	A	A	A
	Alums	all types	A	A	A	A
	Ammonia	100% dry gas	A	A	A	A
	Ammonium Carbonate		A	A	A	A
	Ammonium Chloride	sat'd	A	A	A	A
	Ammonium Fluoride	sat'd	A	A	A	A
	Ammonium Hydroxide	10%	A	A	A	A
	Ammonium Hydroxide	28%	A	A	A	A
	Ammonium Nitrate	sat'd	A	A	A	A
	Ammonium Persulphate	sat'd	A	A	A	A
	Ammonium Sulphate	sat'd	A	A	A	A
	Ammonium Metaphosphate	sat'd	A	A	A	A
	Ammonium Sulfide	sat'd	A	A	A	A
	Amyl Acetate#*	100%	C	C	C	C
	Amyl Alcohol#*	100%	A	A	A	A
	Amyl Chloride#	100%	C	C	C	C
	Aniline#*	100%	A	C	C	B
	Aqua Regia+		C	C	C	C
	Arsenic Acid	all conc	A	A	A	A
	Aromatic Hydrocarbons#*		C	C	C	C
	Ascorbic Acid	10%	A	A	A	A
	Barium Carbonate	sat'd	A	A	A	A
	Barium Chloride	sat'd	A	A	A	A
	Barium Hydroxide		A	A	A	A
	Barium Sulphate	sat'd	A	A	A	A
	Barium Sulphide	sat'd	A	A	A	A
	Beer		A	A	A	A
	Benzene#*		C	C	C	C

**CODES**

- A** Resistant no indication that serviceability would be impaired.
- B** Variable resistance, depending on conditions of use.
- C** Unresistant, not recommended for service applications under any conditions.
- Information not available.

**# Plasticizer.**

Certain types of chemicals are absorbed to varying degrees by polyethylene causing swelling, weight-gain, softening and some loss of yield strength. These plasticizing materials cause no actual chemical degradation of the resin. Several of these chemicals have a strong plasticizing effect (e.g. aromatic hydrocarbons benzene), whereas others have weaker effects (e.g. gasoline). Certain plasticizers are sufficiently volatile that if they are removed from contact with the polyethylene, the part will "dry" out and return to its original condition with no loss of properties.

**+ Oxidizers.**

Oxidizers are the only group of materials capable of chemically degrading polyethylene. The effects on the polyethylene may be gradual even for strong oxidizers and short-term effects may not be measurable. However, if continuous long-term exposure is intended, the chemical effects should be checked regularly.

Potassium Perchlorate	10%	A	A	A	A
Potassium Permanganate	20%	A	A	A	A
Potassium Persulphate	sat'd	A	A	A	A
Potassium Sulphate	conc	A	A	A	A
Potassium Sulphide	conc	A	A	A	A
Potassium Sulphite	conc	A	A	A	A
Propargyl Alcohol*		A	A	A	A
n-Propyl Alcohol*		A	A	A	A
Propylene Dichloride#*	100%	C	C	C	-
Propylene Glycol*		A	A	A	A
Pyridine*		A	-	A	-
Resorcinol	sat'd	A	A	A	A
Salicylic Acid	sat'd	A	A	A	A
Sea Water		A	A	A	A
Selenic Acid		A	A	A	A
Shortening*		A	A	A	A
Sliver Nitrate Sol'n		A	A	A	A
Soap Solutions*	any conc	A	A	A	A
Sodium Acetate	sat'd	A	A	A	A
Sodium Benzoate	35%	A	A	A	A
Sodium Biscarbonate	sat'd	A	A	A	A
Sodium Bisulphate	sat'd	A	A	A	A
Sodium Bisulphite	sat'd	A	A	A	A
Sodium Borate		A	A	A	A
Sodium Bromide	dilute	A	A	A	A
Sodium Carbonate	conc	A	A	A	A
Sodium Chlorate	sat'd	A	A	A	A
Sodium Chloride	sat'd	A	A	A	A
Sodium Cyanide		A	A	A	A
Sodium Dichromate	sat'd	A	A	A	A
Sodium Ferri/Ferro Cyanide	sat'd	A	A	A	A
Sodium Fluoride	sat'd	A	A	A	A
Sodium Hydroxide	conc	A	A	A	A
Sodium Hypochlorite		A	A	A	A
Sodium Nitrate		A	A	A	A
Sodium Sulphate		A	A	A	A
Sodium Sulphide	sat'd	A	A	A	A
Sodium Sulphite	sat'd	A	A	A	A
Stannic Chloride	sat'd	A	A	A	A
Stannous Chloride	sat'd	A	A	A	A
Starch Solution*	sat'd	A	A	A	A
Stearic Acid*	100%	A	A	A	A
Sulphuric Acid	0-50%	A	A	A	A
Sulphuric Acid+	70%	A	B	A	B
Sulphuric Acid+	80%	A	C	A	C
Sulphuric Acid+	96%	B	C	B	C
Sulphuric Acid+	98-conc	B	C	B	C
Sulphuric Acid+	fuming	C	C	C	C
Sulphurous Acid		A	A	A	A
Tallow#		A	B	A	-
Tannic Acid*	sat'd	A	A	A	A
Tartaric Acid		A	A	A	A
Tetrohydrofuran#*		C	C	B	C
Titanium Tetrochloride	sat'd	C	C	C	-
Toluene#*		C	C	B	B
Trichloroethylene#*		C	C	C	C
Triethylene Glycol*		A	A	A	A
Trisodium Phosphate	sat'd	A	A	A	A

**A.4.5: Heuristic 34 (Seider et al. 2017)**

- “Heuristic 34: Use a fan to raise the gas pressure from atmospheric pressure to as high as 40 inches water gauge (10.1 kPa gauge or 1.47 psig). Use a blower or compressor to raise the gas pressure to as high as 206 kPa gauge or 30 psig. Use a compressor or a staged compressor system to attain pressures greater than 206 kPa gauge or 30 psig.”

## A.5: ASPEN Input and Output Files

### A.5.1: Valve P and T Change Test

#### A.5.1.1: Input File

```
;
;Input Summary created by Aspen Plus Rel. 36.0 at 01:10:44 Tue Apr 17, 2018
;Directory \\nestor\leconnor\CBE459\Valve CH4 P drop Filename
C:\Users\leconnor\AppData\Local\Temp\~ape89d.txt
;

DYNAMICS
  DYNAMICS RESULTS=ON

IN-UNITS ENG SHORT-LENGTH=in

DEF-STREAMS CONVEN ALL

DATABANKS 'APV100 PURE36' / 'APV100 AQUEOUS' / 'APV100 SOLIDS' &
  / 'APV100 INORGANIC' / 'APESV100 AP-EOS' / &
  'NISTV100 NIST-TRC' / NOASPENPCD

PROP-SOURCES 'APV100 PURE36' / 'APV100 AQUEOUS' / &
  'APV100 SOLIDS' / 'APV100 INORGANIC' / 'APESV100 AP-EOS' &
  / 'NISTV100 NIST-TRC'

COMPONENTS
  CH4 CH4

SOLVE
  RUN-MODE MODE=SIM

FLOWSHEET
  BLOCK VALVE IN=1 OUT=2

PROPERTIES ENRTL-RK

STREAM 1
  SUBSTREAM MIXED TEMP=70. PRES=514.6959488 MASS-FLOW=21015.
  MOLE-FRAC CH4 1.

BLOCK VALVE VALVE
  PARAM P-OUT=24.69594878 NPHASE=1 PHASE=V
  BLOCK-OPTION FREE-WATER=NO

EO-CONV-OPTI

STREAM-REPOR MOLEFLOW
;
;
;
;
;
```

### A.5.1.2: Stream Report

1	2	
---	---	
STREAM ID	1	2
FROM :	----	VALVE
TO :	VALVE	----
SUBSTREAM: MIXED		
PHASE:	VAPOR	VAPOR
COMPONENTS: LBMOL/HR		
CH4	1309.9367	1309.9367
TOTAL FLOW:		
LBMOL/HR	1309.9367	1309.9367
LB/HR	2.1015+04	2.1015+04
CUFT/HR	1.3522+04	2.8421+05
STATE VARIABLES:		
TEMP F	70.0000	41.5954
PRES PSIA	514.6959	24.6959
VFRAC	1.0000	1.0000
LFRAC	0.0	0.0
SFRAC	0.0	0.0
ENTHALPY:		
BTU/LBMOL	-3.2350+04	-3.2350+04
BTU/LB	-2016.4667	-2016.4667
BTU/HR	-4.2376+07	-4.2376+07
ENTROPY:		
BTU/LBMOL-R	-26.7674	-20.8752
BTU/LB-R	-1.6685	-1.3012
DENSITY:		
LBMOL/CUFT	9.6872-02	4.6091-03
LB/CUFT	1.5541	7.3942-02
AVG MW	16.0428	16.0428

## A.5.2: Air Stripping Column Simulation without Acid

### A.5.2.1: Input File

- This is an example of an ASPEN simulation that helped us optimize the stripping column. Since there is no one perfect simulation, the inputs and results from this simulation may not match the specifications, required outputs, or column sizing data; and this is expected. This specific run is for the 20-tray column with 25% Murphree Efficiency, Design Specified to reduce ammonia to 16 ppm (so that ammonia plus ammonium are together less than 20 ppm), for the maximum sour water flow rate and ammonia concentration.

```

;
;Input Summary created by Aspen Plus Rel. 36.0 at 03:52:55 Tue Apr 17,
2018
;Directory \\nestor\leconnor\CBE459 Filename
C:\Users\leconnor\AppData\Local\Temp\~ap654e.txt
;

DYNAMICS
  DYNAMICS RESULTS=ON

IN-UNITS ENG SHORT-LENGTH=in

DEF-STREAMS CONVEN ALL

MODEL-OPTION

DESCRIPTION "
  Electrolytes Simulation with English Units :
  F, psi, lb/hr, lbmol/hr, Btu/hr, cuft/hr.

  Property Method: ELECNRTL

  Flow basis for input: Mass

  Stream report composition: Mass flow
"

DATABANKS 'APV100 ASPENPCD' / 'APV100 AQUEOUS' / 'APV100 SOLIDS' &
  / 'APV100 INORGANIC' / 'APV100 PURE36'

PROP-SOURCES 'APV100 ASPENPCD' / 'APV100 AQUEOUS' / &
  'APV100 SOLIDS' / 'APV100 INORGANIC' / 'APV100 PURE36'

COMPONENTS
  H2O H2O /
  H2S H2S /
  NH3 H3N /
  N2 N2 /
  O2 O2 /
  H3O+ H3O+ /
  NH4+ NH4+ /
  HS- HS- /
  OH- OH- /
  S-- S-2

HENRY-COMPS GLOBAL H2S NH3 O2 N2

SOLVE

```

RUN-MODE MODE=SIM

CHEMISTRY GLOBAL

PARAM GAMMA-BASIS=UNSYMMETRIC

STOIC 1 NH3 -1 / H2O -1 / OH- 1 / NH4+ 1

STOIC 2 H2O -1 / HS- -1 / H3O+ 1 / S-- 1

STOIC 3 H2O -1 / H2S -1 / H3O+ 1 / HS- 1

STOIC 4 H2O -2 / OH- 1 / H3O+ 1

K-STOIC 1 A=-1.256563 B=-3335.699951 C=1.4971 D=-0.037057

K-STOIC 2 A=-9.741963 B=-8585.469727 C=0 D=0

K-STOIC 3 A=214.582443 B=-12995.400391 C=-33.5471 D=0

K-STOIC 4 A=132.89888 B=-13445.900391 C=-22.477301 D=0

FLOWSHEET

BLOCK STRIPPER IN=SOURWATR AIRFEED OUT=EXTRACT RAFINATE &

S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 &

S15 S16

PROPERTIES ENRTL-RK HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL &

TRUE-COMPS=NO

PROPERTIES ELECNRTL

PROP-DATA HENRY-1

IN-UNITS ENG PRESSURE=psi PDROP=psi SHORT-LENGTH=in

PROP-LIST HENRY

BPVAL H2S H2O 381.6601370 -23826.24000 -55.05510000 &  
.0330916666 31.73000000 301.7300000 0.0

BPVAL NH3 H2O -158.8183807 -283.5936000 28.10010000 &  
-.0273483333 31.73000000 436.7300000 0.0

BPVAL N2 H2O 180.3399883 -15178.98600 -21.55800000 &  
-4.6868000E-3 31.73000000 163.1300000 0.0

BPVAL O2 H2O 157.8962298 -13995.10800 -18.39740000 &  
-5.2464111E-3 33.53000000 166.7300000 0.0

BPVAL N2 NH3 10.80598441 0.0 0.0 0.0 67.73000000 &  
67.73000000 0.0

BPVAL O2 NH3 11.20948341 0.0 0.0 0.0 67.73000000 &  
67.73000000 0.0

PROP-DATA NRTL-1

IN-UNITS ENG SHORT-LENGTH=in

PROP-LIST NRTL

BPVAL H2O H2S -3.674000000 2080.620000 .2000000000 0.0 0.0 &  
0.0 32.00000000 302.0000000

BPVAL H2S H2O -3.674000000 2080.620000 .2000000000 0.0 0.0 &  
0.0 32.00000000 302.0000000

BPVAL H2O NH3 -.5440720000 3021.244200 .2000000000 0.0 0.0 &  
0.0 32.00000000 392.0000000

BPVAL NH3 H2O -.1642422000 -1849.545000 .2000000000 0.0 &  
0.0 0.0 32.00000000 392.0000000

PROP-DATA GMELCC-1

IN-UNITS ENG SHORT-LENGTH=in

PROP-LIST GMELCC

PPVAL H2O ( H3O+ HS- ) 8.045000000

PPVAL ( H3O+ HS- ) H2O -4.072000000

PPVAL H2O ( H3O+ OH- ) 8.045000000

PPVAL ( H3O+ OH- ) H2O -4.072000000

PPVAL H2O ( H3O+ S-- ) 8.045000000

PPVAL ( H3O+ S-- ) H2O -4.072000000

PPVAL H2O ( NH4+ HS- ) 8.060565000

PPVAL ( NH4+ HS- ) H2O -4.326618000

PPVAL H2O ( NH4+ OH- ) 8.045000000

PPVAL ( NH4+ OH- ) H2O -4.072000000

PPVAL H2O ( NH4+ S-- ) 8.045000000

```

PPVAL ( NH4+ S-- ) H2O -4.072000000
PPVAL H2S ( H3O+ HS- ) 15.000000000
PPVAL ( H3O+ HS- ) H2S -8.000000000
PPVAL H2S ( H3O+ OH- ) 15.000000000
PPVAL ( H3O+ OH- ) H2S -8.000000000
PPVAL H2S ( H3O+ S-- ) 15.000000000
PPVAL ( H3O+ S-- ) H2S -8.000000000
PPVAL H2S ( NH4+ HS- ) 10.000000000
PPVAL ( NH4+ HS- ) H2S -4.000000000
PPVAL NH3 ( NH4+ HS- ) 50.000000000
PPVAL ( NH4+ HS- ) NH3 -2.850924000

```

PROP-DATA GMELCD-1

```

IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMELCD
PPVAL H2O ( NH4+ HS- ) -85.25541600
PPVAL ( NH4+ HS- ) H2O 158.0140800
PPVAL H2S ( H3O+ HS- ) 0.0
PPVAL ( H3O+ HS- ) H2S 0.0
PPVAL H2S ( H3O+ OH- ) 0.0
PPVAL ( H3O+ OH- ) H2S 0.0
PPVAL H2S ( H3O+ S-- ) 0.0
PPVAL ( H3O+ S-- ) H2S 0.0

```

PROP-DATA GMELCE-1

```

IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMELCE
PPVAL H2S ( H3O+ HS- ) 0.0
PPVAL ( H3O+ HS- ) H2S 0.0
PPVAL H2S ( H3O+ OH- ) 0.0
PPVAL ( H3O+ OH- ) H2S 0.0
PPVAL H2S ( H3O+ S-- ) 0.0
PPVAL ( H3O+ S-- ) H2S 0.0

```

PROP-DATA GMELCN-1

```

IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMELCN
PPVAL H2S ( H3O+ HS- ) .1000000000
PPVAL H2S ( H3O+ OH- ) .1000000000
PPVAL H2S ( H3O+ S-- ) .1000000000

```

PROP-DATA GMENCC-1

```

IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMENCC
PPVAL H2O ( H3O+ HS- ) 8.045000000
PPVAL ( H3O+ HS- ) H2O -4.072000000
PPVAL H2O ( H3O+ OH- ) 8.045000000
PPVAL ( H3O+ OH- ) H2O -4.072000000
PPVAL H2O ( H3O+ S-- ) 8.045000000
PPVAL ( H3O+ S-- ) H2O -4.072000000
PPVAL H2O ( NH4+ HS- ) 8.060565000
PPVAL ( NH4+ HS- ) H2O -4.326618000
PPVAL H2O ( NH4+ OH- ) 8.045000000
PPVAL ( NH4+ OH- ) H2O -4.072000000
PPVAL H2O ( NH4+ S-- ) 8.045000000
PPVAL ( NH4+ S-- ) H2O -4.072000000

```

PROP-DATA GMENCD-1

```

IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMENCD
PPVAL H2O ( NH4+ HS- ) -85.25541600
PPVAL ( NH4+ HS- ) H2O 158.0140800

```

STREAM AIRFEED



```

SUBSTREAM MIXED TEMP=190. PRES=35. MASS-FLOW=33792.71516
MOLE-FRAC H2O 0.1 / N2 0.711 / O2 0.189

STREAM SOURWATR
SUBSTREAM MIXED TEMP=190. PRES=25. MASS-FLOW=25000.
MASS-FRAC H2O 0.996995 / H2S 5E-006 / NH3 0.003

BLOCK STRIPPER RADFRAC
SUBJECTS INTERNALS = CS-1
PARAM NSTAGE=20 ALGORITHM=STANDARD EFF=MURPHREE ABSORBER=YES &
HYDRAULIC=NO MAXOL=200 DAMPING=NONE
PARAM2 STATIC-DP=YES
COL-CONFIG CONDENSER=NONE REBOILER=NONE CA-CONFIG=INT-1
FEEDS SOURWATR 1 / AIRFEED 20 ON-STAGE
PRODUCTS RAFINATE 20 L / EXTRACT 1 V
PSEUDO-STREA S1 1 MOLE-FLOW=1E-005 / S2 2 &
MOLE-FLOW=1E-005 / S3 3 MOLE-FLOW=1E-005 / S4 4 &
MOLE-FLOW=1E-005 / S5 5 MOLE-FLOW=1E-005 / S6 6 &
MOLE-FLOW=1E-005 / S7 7 MOLE-FLOW=1E-005 / S8 8 &
MOLE-FLOW=1E-005 / S9 9 MOLE-FLOW=1E-005 / S10 10 &
MOLE-FLOW=1E-005 / S11 11 MOLE-FLOW=1E-005 / S12 12 &
MOLE-FLOW=1E-005 / S13 13 MOLE-FLOW=1E-005 / S14 14 &
MOLE-FLOW=1E-005 / S15 15 MOLE-FLOW=1E-005 / S16 16 &
MOLE-FLOW=1E-005
P-SPEC 1 17.
COL-SPECS DP-STAGE=0.1 DP-COND=0.
PROPERTIES ENRTL-RK HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL &
FREE-WATER=STEAM-TA SOLU-WATER=3 TRUE-COMPS=YES
REPORT NOHYDRAULIC
STEFF-SEC SECNO=1 1 20 0.25
INTERNALS CS-1 STAGE1=1 STAGE2=20 P-UPDATE=NO
TRAY-SIZE 1 1 20 SIEVE

DESIGN-SPEC DS-1
DEFINE NH3 MASS-FRAC STREAM=RAFINATE SUBSTREAM=MIXED &
COMPONENT=NH3
SPEC "NH3" TO "16e-06"
TOL-SPEC ".1e-07"
VARY STREAM-VAR STREAM=AIRFEED SUBSTREAM=MIXED &
VARIABLE=MASS-FLOW UOM="lb/hr"
LIMITS "8000" "45000"

EO-CONV-OPTI

CONV-OPTIONS
PARAM TEAR-METHOD=BROYDEN SPEC-METHOD=BROYDEN

STREAM-REPOR MOLEFLOW MASSFLOW
:
:
:
:
:
:
:
:

```

**A.5.2.2: Output File**

```

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PLATFORM: WINDOWS                    APRIL 17, 2018
VERSION: 36.0  Build 249               TUESDAY
INSTALLATION:                           9:52:22 A.M.

ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/17/2018 PAGE I

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```

```

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RUN CONTROL SECTION

RUN CONTROL INFORMATION

THIS COPY OF ASPEN PLUS LICENSED TO UNIVERSITY OF PENNSYLVAN

TYPE OF RUN: NEW

INPUT FILE NAME: \_4940mjpg.inm

OUTPUT PROBLEM DATA FILE NAME: \_4940mjpg  
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:  
NUMBER OF FILE RECORDS (PSIZE) = 0  
NUMBER OF IN-CORE RECORDS = 256  
PSIZE NEEDED FOR SIMULATION = 256

CALLING PROGRAM NAME: apmain  
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V10.0\Engine\ \xeq

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

DESCRIPTION

Electrolytes Simulation with English Units : F, psi, lb/hr,  
lbmol/hr, Btu/hr, cuft/hr. Property Method: ELECNRTL Flow basis  
for input: Mass Stream report composition: Mass flow

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FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
AIRFEED	----	STRIPPER	SOURWATR	----	STRIPPER
EXTRACT	STRIPPER	----	RAFINATE	STRIPPER	----
S1	STRIPPER	----	S2	STRIPPER	----
S3	STRIPPER	----	S4	STRIPPER	----
S5	STRIPPER	----	S6	STRIPPER	----
S7	STRIPPER	----	S8	STRIPPER	----
S9	STRIPPER	----	S10	STRIPPER	----
S11	STRIPPER	----	S12	STRIPPER	----
S13	STRIPPER	----	S14	STRIPPER	----

S15	STRIPPER	----	S16	STRIPPER	----	
<p>FLWSHEET CONNECTIVITY BY BLOCKS</p> <p>-----</p>						
BLOCK	INLETS		OUTLETS			
STRIPPER	SOURWATR AIRFEED		EXTRACT RAFINATE S1 S2 S3			
			S4 S5 S6 S7 S8 S9 S10 S11			
			S12 S13 S14 S15 S16			
<p>CONVERGENCE STATUS SUMMARY</p> <p>-----</p>						
<p>DESIGN-SPEC SUMMARY</p> <p>=====</p>						
DESIGN SPEC	ERROR	TOLERANCE	ERR/TOL	VARIABLE	STAT	CONV BLOCK
-----	-----	-----	-----	-----	-----	-----
DS-1	-0.87165E-08	0.10000E-07	-0.87165	28984.	#	
\$OLVER01						
#	= CONVERGED					
*	= NOT CONVERGED					
LB	= AT LOWER BOUNDS					
UB	= AT UPPER BOUNDS					
DESIGN-SPEC: DS-1						
-----						
SAMPLED VARIABLES:						
NH3	:	NH3 MASSFRAC IN STREAM RAFINATE SUBSTREAM MIXED				
SPECIFICATION:						
MAKE NH3 APPROACH	:	0.160000-04				
WITHIN	:	0.100000-07				
MANIPULATED VARIABLES:						
VARY	:	TOTAL MASSFLOW IN STREAM AIRFEED SUBSTREAM MIXED				
LOWER LIMIT =	:	8,000.00				LB/HR
UPPER LIMIT =	:	45,000.0				LB/HR
FINAL VALUE =	:	28,983.7				LB/HR
<p>ASPEN PLUS PLAT: WINDOWS VER: 36.0 04/17/201 PAGE 3</p> <p>FLWSHEET SECTION</p>						
DESIGN-SPEC: DS-1 (CONTINUED)						
VALUES OF ACCESSED FORTRAN VARIABLES:						
VARIABLE	VALUE AT START OF LOOP	FINAL VALUE	UNITS			
-----	-----	-----	-----			
NH3	0.652506E-05	0.159913E-04				
CONVERGENCE BLOCK: \$OLVER01						
-----						
SPECS: DS-1						
MAXIT =	:	30				
PERTURBATION SIZE (% OF RANGE):	:	DS-1	1.0000			
MAXIMUM STEP SIZE (% OF RANGE):	:	DS-1	100.00			
METHOD: BROYDEN	:	STATUS: CONVERGED				

TOTAL NUMBER OF ITERATIONS: 7

\*\*\* FINAL VALUES \*\*\*

VAR#	MANIPUL/TEAR-VAR	VARIABLE DESCRIPTION	UNIT
	VALUE	PREV VALUE	ERR/TOL
1	TOTAL MASSFLOW	AIRFEED.MIXED.TOTAL.MASSFLOW	LB/HR
2.8984+04	2.8915+04	-0.8716	

\*\*\* ITERATION HISTORY \*\*\*

DESIGN-SPEC ID: DS-1  
ITERATED: TOTAL MASSFLOW IN STREAM AIRFEED SUBSTREAM MIXED

ITERATION	VARIABLE	ERROR	ERR/TOL
1	0.3379E+05	-0.9475E-05	-947.5
2	0.3416E+05	-0.9921E-05	-992.1
3	0.2593E+05	0.1284E-04	1284.
4	0.3045E+05	-0.3800E-05	-380.0
5	0.2942E+05	-0.1247E-05	-124.7
6	0.2891E+05	0.1970E-06	19.70
7	0.2898E+05	-0.8716E-08	-0.8716

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:  
\$SOLVER01 STRIPPER  
(RETURN \$SOLVER01)

OVERALL FLOWSHEET BALANCE

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FLOWSHEET SECTION

OVERALL FLOWSHEET BALANCE (CONTINUED)

DIFF.	CONVENTIONAL COMPONENTS (LBMOL/HR)	*** MASS AND ENERGY BALANCE IN	OUT	*** GENERATION	RELATIVE
0.287289E-13	H2O	1487.88	1487.92	0.429045E-01	-
0.727349E-13	H2S	0.223004E-05	0.170229E-02	0.170006E-02	
0.934697E-13	NH3	4.35497	4.39957	0.446078E-01	-
0.480999E-13	N2	742.157	742.157	0.00000	
0.350081E-13	O2	197.282	197.282	0.00000	
0.238120E-11	H3O+	0.607576E-08	0.206218E-07	0.145461E-07	
0.230669E-15	NH4+	0.488827E-01	0.427494E-02	-0.446078E-01	

HS-	0.366215E-02	0.196531E-02	-0.169684E-02
0.118422E-15			
OH-	0.452141E-01	0.230957E-02	-0.429045E-01
0.335710E-15			
S--	0.325827E-05	0.421339E-07	-0.321614E-05
0.211221E-15			
TOTAL BALANCE			
MOLE(LBMOL/HR)	2431.77	2431.77	-0.105165E-12
0.187003E-15			
MASS(LB/HR )	53983.7	53983.7	
0.862597E-14			
ENTHALPY(BTU/HR )	-0.177480E+09	-0.177480E+09	
0.271437E-07			

\*\*\* CO2 EQUIVALENT SUMMARY \*\*\*

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

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PHYSICAL PROPERTIES SECTION

COMPONENTS

ID	TYPE	ALIAS	NAME
H2O	C	H2O	WATER
H2S	C	H2S	HYDROGEN-SULFIDE
NH3	C	H3N	AMMONIA
N2	C	N2	NITROGEN
O2	C	O2	OXYGEN
H3O+	C	H3O+	H3O+
NH4+	C	NH4+	NH4+
HS-	C	HS-	HS-
OH-	C	OH-	OH-
S--	C	S-2	S--

LISTID SUPERCRITICAL COMPONENT LIST  
GLOBAL H2S NH3 O2 N2

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC

INLETS	- SOURWATR	STAGE	1
	AIRFEED	STAGE	20
OUTLETS	- EXTRACT	STAGE	1
	RAFINATE	STAGE	20
	S1	STAGE	1
	S2	STAGE	2
	S3	STAGE	3
	S4	STAGE	4
	S5	STAGE	5
	S6	STAGE	6
	S7	STAGE	7
	S8	STAGE	8
	S9	STAGE	9

```

S10      STAGE 10
S11      STAGE 11
S12      STAGE 12
S13      STAGE 13
S14      STAGE 14
S15      STAGE 15
S16      STAGE 16
PROPERTY OPTION SET:  ENRTL-RK  ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID:      GLOBAL
CHEMISTRY ID:        GLOBAL  - TRUE SPECIES

***  MASS AND ENERGY BALANCE  ***
          IN                OUT          GENERATION  RELATIVE
DIFF.
TOTAL BALANCE
MOLE(LBMOL/HR)                2431.77          2431.77          -0.105165E-12  -
0.374005E-15
MASS(LB/HR )                   53983.7           53983.7
0.835640E-14
ENTHALPY(BTU/HR )              -0.177480E+09     -0.177480E+09
0.271437E-07

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

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          U-O-S BLOCK SECTION

BLOCK:  STRIPPER MODEL: RADFRAC (CONTINUED)

*****
***** INPUT DATA *****
*****

****  INPUT PARAMETERS  ****

NUMBER OF STAGES                20
ALGORITHM OPTION                STANDARD
INITIALIZATION OPTION           STANDARD
HYDRAULIC PARAMETER CALCULATIONS  NO
INSIDE LOOP CONVERGENCE METHOD    NEWTON
DESIGN SPECIFICATION METHOD       NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS  200
MAXIMUM NO. OF INSIDE LOOP ITERATIONS  10
MAXIMUM NUMBER OF FLASH ITERATIONS  30
FLASH TOLERANCE                  0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE  0.000100000

****  COL-SPECS  ****

MOLAR VAPOR DIST / TOTAL DIST  1.00000
CONDENSER DUTY (W/O SUBCOOL)    BTU/HR  0.0
REBOILER DUTY                   BTU/HR  0.0

****  REAC-STAGES SPECIFICATIONS  ****

```

STAGE 1	TO	STAGE 20	REACTIONS/CHEMISTRY ID GLOBAL		
***** CHEMISTRY PARAGRAPH GLOBAL *****					
**** REACTION PARAMETERS ****					
RXN NO.	TYPE	PHASE	CONC.	TEMP	APP TO EQUIL
CONVERSION					
			BASIS		F
1	EQUILIBRIUM	LIQUID	MOLE - GAMMA		0.0000
2	EQUILIBRIUM	LIQUID	MOLE - GAMMA		0.0000
3	EQUILIBRIUM	LIQUID	MOLE - GAMMA		0.0000
4	EQUILIBRIUM	LIQUID	MOLE - GAMMA		0.0000
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U-O-S BLOCK SECTION					
BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)					
** STOICHIOMETRIC COEFFICIENTS **					
RXN NO.	H2O	H2S	NH3	N2	O2
1	-1.000	0.000	-1.000	0.000	0.000
2	-1.000	0.000	0.000	0.000	0.000
3	-1.000	-1.000	0.000	0.000	0.000
4	-2.000	0.000	0.000	0.000	0.000
RXN NO.	H3O+	NH4+	HS-	OH-	S--
1	0.000	1.000	0.000	1.000	0.000
2	1.000	0.000	-1.000	0.000	1.000
3	1.000	0.000	1.000	0.000	0.000
4	1.000	0.000	0.000	1.000	0.000
** COEFFICIENTS OF EQUILIBRIUM CONSTANT EXPRESSION **					
RXN NO.	A	B	C	D	E
1	-1.2566	-3335.7	1.4971	-0.37057E-01	0.0000
2	-9.7420	-8585.5	0.0000	0.0000	0.0000
3	214.58	-12995.	-33.547	0.0000	0.0000
4	132.90	-13446.	-22.477	0.0000	0.0000
**** PROFILES ****					
P-SPEC	STAGE	1	PRES, PSIA		17.0000
**** TRAY MURPHREE EFFICIENCY ****					
	SEGMENT	1	20	EFFICIENCY	0.25000
*****					
**** RESULTS ****					
*****					



\*\*\* COMPONENT SPLIT FRACTIONS \*\*\*

COMPONENT:	OUTLET STREAMS	
	EXTRACT	RAFINATE
H2O	.12606	.87394
H2S	.99563	.43664E-02
NH3	.99500	.49999E-02
N2	.99999	.13549E-04
O2	.99998	.24540E-04
H3O+	0.0000	1.0000
NH4+	0.0000	1.0000
HS-	0.0000	1.0000
OH-	0.0000	1.0000
S--	0.0000	1.0000

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

\*\*\* SUMMARY OF KEY RESULTS \*\*\*

TOP STAGE TEMPERATURE	F	155.993
BOTTOM STAGE TEMPERATURE	F	136.007
TOP STAGE LIQUID FLOW	LBMOL/HR	1,347.02
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	1,300.40
TOP STAGE VAPOR FLOW	LBMOL/HR	1,131.37
BOILUP VAPOR FLOW	LBMOL/HR	1,055.55
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	0.0
REBOILER DUTY	BTU/HR	0.0

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

BUBBLE POINT	0.14748E-06	STAGE= 7
COMPONENT MASS BALANCE	0.43421E-12	STAGE= 1 COMP=H2S
ENERGY BALANCE	0.25465E-09	STAGE= 1

\*\*\*\* PROFILES \*\*\*\*

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

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL		HEAT DUTY BTU/HR
			LIQUID	VAPOR	
1	155.99	17.000	-0.12137E+06	-16763.	
2	140.87	17.000	-0.12170E+06	-13763.	
9	124.61	17.700	-0.12208E+06	-11086.	
10	124.71	17.800	-0.12208E+06	-11083.	
11	124.88	17.900	-0.12208E+06	-11090.	
19	128.26	18.700	-0.12204E+06	-11207.	
20	136.01	18.800	-0.12190E+06	-11029.	

STAGE	FLOW RATE LBMOL/HR		FEED RATE LBMOL/HR			PRODUCT RATE LBMOL/HR
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID
VAPOR						

1	1347.	1131.	1387.9483		
	1131.3678				
2	1330.	1090.			
9	1312.	1056.			
10	1312.	1056.			
11	1312.	1056.			
19	1312.	1057.			
20	1300.	1056.		1043.8212	1300.4017

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

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

STAGE	FLOW RATE LB/HR		FEED RATE LB/HR			PRODUCT RATE LB/HR
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID
VAPOR						
1	0.2426E+05	0.3056E+05	.25000+05			
	.30556+05					
2	0.2396E+05	0.2982E+05				
9	0.2364E+05	0.2920E+05				
10	0.2364E+05	0.2919E+05				
11	0.2364E+05	0.2920E+05				
19	0.2364E+05	0.2922E+05				
20	0.2343E+05	0.2919E+05			.28984+05	.23427+05

STAGE	H2O	**** MOLE-X-PROFILE ****			O2
		H2S	NH3	N2	
1	0.99809	0.11251E-08	0.18498E-02	0.59181E-05	
	0.27690E-05				
2	0.99866	0.10797E-08	0.12793E-02	0.66658E-05	
	0.31874E-05				
9	0.99971	0.38670E-08	0.25581E-03	0.77533E-05	
	0.37928E-05				
10	0.99976	0.47792E-08	0.20823E-03	0.77964E-05	
	0.38134E-05				
11	0.99980	0.58110E-08	0.16925E-03	0.78359E-05	
	0.38318E-05				
19	0.99995	0.68166E-08	0.25225E-04	0.80558E-05	
	0.39209E-05				
20	0.99997	0.57159E-08	0.16916E-04	0.77325E-05	
	0.37229E-05				

STAGE	H3O+	**** MOLE-X-PROFILE ****			S--
		NH4+	HS-	OH-	
1	0.22679E-11	0.27981E-04	0.27795E-05	0.25199E-04	
	0.11790E-08				
2	0.17480E-11	0.23584E-04	0.29741E-05	0.20608E-04	
	0.83477E-09				
9	0.27966E-11	0.12662E-04	0.53462E-05	0.73152E-05	
	0.41991E-09				
10	0.32538E-11	0.11953E-04	0.56671E-05	0.62852E-05	
	0.38220E-09				
11	0.38016E-11	0.11286E-04	0.58921E-05	0.53932E-05	
	0.34114E-09				
19	0.11098E-10	0.43974E-05	0.23933E-05	0.20040E-05	
	0.52596E-10				

20 0.15858E-10 0.32874E-05 0.15113E-05 0.17760E-05  
0.32401E-10

\*\*\*\* MOLE-Y-PROFILE \*\*\*\*

STAGE	H2O	H2S	NH3	N2	O2
1	0.16579	0.14981E-05	0.38693E-02	0.65597	0.17437
2	0.13618	0.16272E-05	0.22956E-02	0.68060	0.18092
9	0.10969	0.43145E-05	0.38234E-03	0.70304	0.18688
10	0.10968	0.47821E-05	0.30884E-03	0.70311	0.18690
11	0.10977	0.51821E-05	0.24881E-03	0.70308	0.18690
19	0.11116	0.20911E-05	0.24162E-04	0.70216	0.18665
20	0.10999	0.11146E-05	0.11933E-04	0.70310	0.18690

\*\*\*\* MOLE-Y-PROFILE \*\*\*\*

STAGE	H3O+	NH4+	HS-	OH-	S--
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

\*\*\*\* K-VALUES \*\*\*\*

STAGE	H2O	H2S	NH3	N2	O2
1	0.25509	987.19	4.6439	98356.	55878.
2	0.17531	889.31	3.4495	97242.	54059.
9	0.10975	752.93	2.3565	90651.	49260.
10	0.10942	749.55	2.3481	90194.	49018.
11	0.10933	746.68	2.3437	89757.	48793.
19	0.11468	736.54	2.4121	86814.	47414.
20	0.13995	780.01	2.8218	87864.	48511.

\*\*\*\* K-VALUES \*\*\*\*

STAGE	H3O+	NH4+	HS-	OH-	S--
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000

\*\*\*\* RATES OF GENERATION \*\*\*\*

LBMOL/HR

STAGE	H2O	H2S	NH3	N2	O2
H3O+					
1	0.1127E-01	-.8020E-04	0.1119E-01	0.000	0.000
.3020E-08					
2	0.6535E-02	-.2110E-03	0.6324E-02	0.000	0.000
.7302E-09					
9	0.1538E-02	-.4922E-03	0.1046E-02	0.000	0.000
0.4899E-09					
10	0.1351E-02	-.4212E-03	0.9301E-03	0.000	0.000
0.5999E-09					

11	0.1170E-02	-.2960E-03	0.8739E-03	0.000	0.000
0.7193E-09					
19	0.2822E-03	0.1032E-02	0.1314E-02	0.000	0.000
0.1895E-08					
20	0.3200E-03	0.1175E-02	0.1495E-02	0.000	0.000
0.6060E-08					
**** RATES OF GENERATION ****					
LBMOL/HR					
STAGE	NH4+	HS-	OH-	S--	
1	-.1119E-01	0.8187E-04	-.1127E-01	-.1670E-05	
2	-.6324E-02	0.2115E-03	-.6535E-02	-.4779E-06	
9	-.1046E-02	0.4922E-03	-.1538E-02	-.4488E-07	
10	-.9301E-03	0.4212E-03	-.1351E-02	-.4946E-07	
11	-.8739E-03	0.2960E-03	-.1170E-02	-.5384E-07	
19	-.1314E-02	-.1032E-02	-.2823E-03	-.3103E-07	
20	-.1495E-02	-.1175E-02	-.3200E-03	-.2688E-07	
**** MASS-X-PROFILE ****					
STAGE	H2O	H2S	NH3	N2	O2
1	0.99818	0.21287E-08	0.17489E-02	0.92035E-05	
0.49187E-05					
2	0.99873	0.20427E-08	0.12094E-02	0.10366E-04	
0.56617E-05					
9	0.99971	0.73158E-08	0.24183E-03	0.12056E-04	
0.67368E-05					
10	0.99976	0.90414E-08	0.19685E-03	0.12123E-04	
0.67733E-05					
11	0.99979	0.10993E-07	0.16000E-03	0.12185E-04	
0.68059E-05					
19	0.99995	0.12896E-07	0.23846E-04	0.12527E-04	
0.69642E-05					
20	0.99996	0.10813E-07	0.15991E-04	0.12024E-04	
0.66125E-05					
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U-O-S BLOCK SECTION					
BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)					
**** MASS-X-PROFILE ****					
STAGE	H3O+	NH4+	HS-	OH-	S--
1	0.23950E-11	0.28019E-04	0.51034E-05	0.23792E-04	
0.20988E-08					
2	0.18458E-11	0.23615E-04	0.54606E-05	0.19457E-04	
0.14860E-08					
9	0.29530E-11	0.12678E-04	0.98152E-05	0.69062E-05	
0.74744E-09					
10	0.34357E-11	0.11968E-04	0.10404E-04	0.59338E-05	
0.68031E-09					
11	0.40142E-11	0.11300E-04	0.10817E-04	0.50916E-05	
0.60722E-09					
19	0.11718E-10	0.44029E-05	0.43938E-05	0.18920E-05	
0.93620E-10					
20	0.16745E-10	0.32915E-05	0.27746E-05	0.16767E-05	
0.57673E-10					
**** MASS-Y-PROFILE ****					
STAGE	H2O	H2S	NH3	N2	O2
1	0.11058	0.18904E-05	0.24398E-02	0.68039	0.20659
2	0.89708E-01	0.20279E-05	0.14295E-02	0.69717	0.21169
9	0.71447E-01	0.53167E-05	0.23543E-03	0.71209	0.21622

10	0.71437E-01	0.58927E-05	0.19017E-03	0.71213	0.21623
11	0.71499E-01	0.63857E-05	0.15321E-03	0.71212	0.21623
19	0.72436E-01	0.25780E-05	0.14884E-04	0.71151	0.21604
20	0.71639E-01	0.13735E-05	0.73479E-05	0.71212	0.21623

\*\*\*\* MASS-Y-PROFILE \*\*\*\*

STAGE	H3O+	NH4+	HS-	OH-	S--
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0000	0.0000	0.0000	0.0000	0.0000

\*\*\*\* MURPHREE EFF \*\*\*\*

STAGE	H2O	H2S	NH3	N2	O2
1	0.25000	0.25000	0.25000	0.25000	0.25000
2	0.25000	0.25000	0.25000	0.25000	0.25000
9	0.25000	0.25000	0.25000	0.25000	0.25000
10	0.25000	0.25000	0.25000	0.25000	0.25000
11	0.25000	0.25000	0.25000	0.25000	0.25000
19	0.25000	0.25000	0.25000	0.25000	0.25000
20	0.25000	0.25000	0.25000	0.25000	0.25000

\*\*\*\* MURPHREE EFF \*\*\*\*

STAGE	H3O+	NH4+	HS-	OH-	S--
1	0.25000	0.25000	0.25000	0.25000	0.25000
2	0.25000	0.25000	0.25000	0.25000	0.25000
9	0.25000	0.25000	0.25000	0.25000	0.25000
10	0.25000	0.25000	0.25000	0.25000	0.25000
11	0.25000	0.25000	0.25000	0.25000	0.25000
19	0.25000	0.25000	0.25000	0.25000	0.25000
20	0.25000	0.25000	0.25000	0.25000	0.25000

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

\*\*\*\*\*  
\*\*\*\*\* HYDRAULIC PARAMETERS \*\*\*\*\*  
\*\*\*\*\*

\*\*\* DEFINITIONS \*\*\*

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

TEMPERATURE F		
STAGE	LIQUID FROM	VAPOR TO
1	155.99	140.87
2	140.87	133.19
9	124.61	124.71
10	124.71	124.88
11	124.88	125.10
19	128.26	136.01
20	136.01	189.49

STAGE	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
	LIQUID	VAPOR	LIQUID	VAPOR	LIQUID	VAPOR
1	24265.	29821.	397.88	0.41293E+06	18.014	27.348
2	23959.	29515.	390.83	0.39895E+06	18.014	27.497
9	23638.	29194.	383.56	0.37148E+06	18.015	27.658
10	23639.	29195.	383.57	0.36953E+06	18.015	27.658
11	23641.	29198.	383.61	0.36766E+06	18.015	27.657
19	23639.	29195.	383.90	0.35854E+06	18.015	27.659
20	23427.	28984.	381.27	0.38654E+06	18.015	27.767

STAGE	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM	
	LIQUID	VAPOR	LIQUID	VAPOR	LIQUID	VAPOR
1	60.985	0.72218E-01	0.41347	0.19458E-01	64.150	65.785
2	61.302	0.73982E-01	0.46981	0.19323E-01	65.785	67.566
9	61.629	0.78589E-01	0.54560	0.19170E-01	67.566	67.558
10	61.629	0.79006E-01	0.54514	0.19174E-01	67.558	67.542
11	61.628	0.79415E-01	0.54427	0.19180E-01	67.542	

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

STAGE	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM	
	LIQUID	VAPOR	LIQUID	VAPOR	LIQUID	VAPOR
19	61.575	0.81427E-01	0.52735	0.19462E-01	67.188	
20	61.445	0.74981E-01	0.49130	0.20855E-01	66.363	

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
2	1.6351	0.28200E-01	13868.	0.10851E+06
9	0.66983E-02	0.28913E-01	13274.	0.10414E+06
10	-.78367E-02	0.28990E-01	13239.	0.10387E+06
11	-.16623E-01	0.29066E-01	13206.	0.10361E+06
19	-.14595	0.29444E-01	13047.	0.10231E+06
20	-.82438	0.28236E-01	13511.	0.10585E+06

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

\*\*\*\*\*

\*\*\*\*\*  
\*\*\* SECTION 1 \*\*\*  
\*\*\*\*\*

STARTING STAGE NUMBER 1  
ENDING STAGE NUMBER 20  
FLOODING CALCULATION METHOD GLITSCH6

DESIGN PARAMETERS  
-----

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

TRAY SPECIFICATIONS  
-----

TRAY TYPE SIEVE  
NUMBER OF PASSES 1  
TRAY SPACING FT 2.00000

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

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

STAGE WITH MAXIMUM DIAMETER 1  
COLUMN DIAMETER FT 4.37737  
DC AREA/COLUMN AREA 0.100000  
DOWNCOMER VELOCITY FT/SEC 0.073440  
FLOW PATH LENGTH FT 3.00747  
SIDE DOWNCOMER WIDTH FT 0.68495  
SIDE WEIR LENGTH FT 3.18065  
CENTER DOWNCOMER WIDTH FT 0.0  
CENTER WEIR LENGTH FT MISSING  
OFF-CENTER DOWNCOMER WIDTH FT 0.0  
OFF-CENTER SHORT WEIR LENGTH FT MISSING  
OFF-CENTER LONG WEIR LENGTH FT MISSING  
TRAY CENTER TO ODC CENTER FT 0.0

\*\*\*\* SIZING PROFILES \*\*\*\*

STAGE	DIAMETER FT	TOTAL AREA SQFT	ACTIVE AREA SQFT	SIDE DC AREA SQFT
1	4.3774	15.049	12.039	1.5049
2	4.3774	15.049	12.039	1.5049
3	4.3774	15.049	12.039	1.5049
4	4.3774	15.049	12.039	1.5049
5	4.3774	15.049	12.039	1.5049
6	4.3774	15.049	12.039	1.5049
7	4.3774	15.049	12.039	1.5049
8	4.3774	15.049	12.039	1.5049
9	4.3774	15.049	12.039	1.5049

10	4.3774	15.049	12.039	1.5049
11	4.3774	15.049	12.039	1.5049
12	4.3774	15.049	12.039	1.5049
13	4.3774	15.049	12.039	1.5049
14	4.3774	15.049	12.039	1.5049
15	4.3774	15.049	12.039	1.5049
16	4.3774	15.049	12.039	1.5049
17	4.3774	15.049	12.039	1.5049
18	4.3774	15.049	12.039	1.5049
19	4.3774	15.049	12.039	1.5049
20	4.3774	15.049	12.039	1.5049

\*\*\*\* ADDITIONAL SIZING PROFILES \*\*\*\*

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
1	80.00	0.1715	0.7852	36.24
2	77.73	0.1608	0.7189	33.18
3	76.46	0.1581	0.7080	32.68
4	75.64	0.1563	0.7013	32.37
5	75.08	0.1552	0.6968	32.16
6	74.64	0.1543	0.6935	32.01
7	74.29	0.1535	0.6909	31.89
8	73.99	0.1529	0.6887	31.78
9	73.72	0.1523	0.6867	31.69
10	73.47	0.1518	0.6849	31.61
11	73.23	0.1513	0.6832	31.53

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
12	73.00	0.1508	0.6816	31.46
13	72.78	0.1503	0.6801	31.39
14	72.56	0.1499	0.6785	31.32
15	72.34	0.1494	0.6770	31.25
16	72.12	0.1490	0.6756	31.18
17	71.92	0.1486	0.6742	31.12
18	71.79	0.1482	0.6733	31.07
19	72.08	0.1488	0.6751	31.16
20	75.57	0.1554	0.6984	32.23

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
1	0.1694	0.6083	0.1696	40.48
2	0.1663	0.6083	0.1708	39.29
3	0.1647	0.6083	0.1716	38.65
4	0.1637	0.6083	0.1720	38.25
5	0.1632	0.6083	0.1724	37.99
6	0.1628	0.6083	0.1727	37.80
7	0.1626	0.6083	0.1729	37.66
8	0.1624	0.6083	0.1731	37.54
9	0.1622	0.6083	0.1733	37.43
10	0.1621	0.6083	0.1734	37.34
11	0.1620	0.6083	0.1736	37.25



12	0.1620	0.6083	0.1737	37.16
13	0.1619	0.6083	0.1739	37.08
14	0.1618	0.6083	0.1740	37.00
15	0.1617	0.6083	0.1742	36.92
16	0.1616	0.6083	0.1743	36.85
17	0.1616	0.6083	0.1745	36.77
18	0.1615	0.6083	0.1746	36.73
19	0.1616	0.6083	0.1744	36.85
20	0.1622	0.6083	0.1723	38.22

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STREAM SECTION

AIRFEED EXTRACT RAFINATE S1 S10

STREAM ID	AIRFEED	EXTRACT	RAFINATE	S1	S10
FROM : STRIPPER	----	STRIPPER	STRIPPER	STRIPPER	
TO :	STRIPPER	----	----	----	----
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	LIQUID	LIQUID	
LIQUID					
COMPONENTS: LBMOL/HR					
H2O	104.3821	187.5644	1300.3562	9.9809-06	9.9976-06
H2S	0.0	1.6949-03	7.4329-06	1.1251-14	4.7792-14
NH3	0.0	4.3776	2.1998-02	1.8498-08	2.0823-09
N2	742.1569	742.1469	1.0055-02	5.9181-11	7.7964-11
O2	197.2822	197.2774	4.8412-03	2.7690-11	3.8134-11
H3O+	0.0	0.0	2.0622-08	2.2679-17	3.2538-17
NH4+	0.0	0.0	4.2749-03	2.7981-10	1.1953-10
HS-	0.0	0.0	1.9653-03	2.7795-11	5.6671-11
OH-	0.0	0.0	2.3096-03	2.5199-10	6.2852-11
S--	0.0	0.0	4.2134-08	1.1790-14	3.8220-15
COMPONENTS: LB/HR					
H2O	1880.4732	3379.0248	2.3426+04	1.7981-04	1.8011-04
H2S	0.0	5.7764-02	2.5333-04	3.8345-13	1.6288-12
NH3	0.0	74.5526	0.3746	3.1504-07	3.5463-08
N2	2.0790+04	2.0790+04	0.2817	1.6579-09	2.1841-09
O2	6312.7943	6312.6394	0.1549	8.8603-10	1.2202-09
H3O+	0.0	0.0	3.9228-07	4.3142-16	6.1895-16
NH4+	0.0	0.0	7.7111-02	5.0472-09	2.1561-09
HS-	0.0	0.0	6.5001-02	9.1930-10	1.8744-09

09	OH-	0.0	0.0	3.9281-02	4.2858-09	1.0690-
13	S--	0.0	0.0	1.3511-06	3.7806-13	1.2256-
05	TOTAL FLOW: LBMOL/HR	1043.8213	1131.3679	1300.4017	1.0000-05	1.0000-
04	LB/HR	2.8984+04	3.0556+04	2.3427+04	1.8014-04	1.8015-
06	CUFT/HR	2.0768+05	4.3917+05	381.2737	2.9538-06	2.9232-
	STATE VARIABLES:					
124.7051	TEMP F	190.0000	155.9929	136.0066	155.9929	
17.8000	PRES PSIA	35.0000	17.0000	18.8000	17.0000	
1.0000	VFRAC	1.0000	1.0000	0.0	0.0	0.0
	LFRAC	0.0	0.0	1.0000	1.0000	
	SFRAC	0.0	0.0	0.0	0.0	0.0
1.2208+05	ENTHALPY: BTU/LBMOL	-9609.4611	-1.6763+04	-1.2190+05	-1.2137+05	-
6776.5742	BTU/LB	-346.0763	-620.6729	-6766.2371	-6737.8567	-
1.2208	BTU/HR	-1.0031+07	-1.8966+07	-1.5851+08	-1.2137	-
37.4502	ENTROPY: BTU/LBMOL-R	0.1280	0.6287	-37.1067	-36.5091	-
2.0788	BTU/LB-R	4.6099-03	2.3278-02	-2.0597	-2.0268	-
3.4209	DENSITY: LBMOL/CUFT	5.0262-03	2.5761-03	3.4107	3.3855	
61.6291	LB/CUFT	0.1396	6.9577-02	61.4448	60.9846	
18.0153	AVG MW	27.7669	27.0084	18.0154	18.0136	

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STREAM SECTION

	S11	S12	S13	S14	S15
STREAM ID	S11	S12	S13	S14	S15
FROM :	STRIPPER	STRIPPER	STRIPPER	STRIPPER	
TO :	----	----	----	----	----
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	
LIQUID					
COMPONENTS: LBMOL/HR					
H2O	9.9980-06	9.9983-06	9.9986-06	9.9988-06	9.9990-
H2S	5.8110-14	6.8936-14	7.9139-14	8.7291-14	9.2003-
NH3	1.6925-09	1.3724-09	1.1093-09	8.9262-10	7.1396-

11	N2	7.8359-11	7.8732-11	7.9093-11	7.9447-11	7.9797-
11	O2	3.8318-11	3.8488-11	3.8652-11	3.8810-11	3.8967-
17	H3O+	3.8016-17	4.4421-17	5.1692-17	5.9684-17	6.8207-
11	NH4+	1.1286-10	1.0616-10	9.9042-11	9.1237-11	8.2664-
11	HS-	5.8921-11	5.9805-11	5.9002-11	5.6369-11	5.1984-
11	OH-	5.3932-11	4.6351-11	4.0035-11	3.4864-11	3.0676-
15	S--	3.4114-15	2.9788-15	2.5414-15	2.1168-15	1.7192-
	COMPONENTS: LB/HR					
04	H2O	1.8012-04	1.8012-04	1.8013-04	1.8013-04	1.8013-
12	H2S	1.9805-12	2.3495-12	2.6972-12	2.9751-12	3.1356-
08	NH3	2.8824-08	2.3373-08	1.8892-08	1.5202-08	1.2159-
09	N2	2.1951-09	2.2056-09	2.2157-09	2.2256-09	2.2354-
09	O2	1.2261-09	1.2316-09	1.2368-09	1.2419-09	1.2469-
15	H3O+	7.2317-16	8.4501-16	9.8331-16	1.1354-15	1.2975-
09	NH4+	2.0358-09	1.9149-09	1.7865-09	1.6457-09	1.4911-
09	HS-	1.9488-09	1.9780-09	1.9515-09	1.8644-09	1.7193-
10	OH-	9.1726-10	7.8833-10	6.8091-10	5.9296-10	5.2174-
14	S--	1.0939-13	9.5522-14	8.1497-14	6.7879-14	5.5130-
	TOTAL FLOW:					
05	LBMOL/HR	1.0000-05	1.0000-05	1.0000-05	1.0000-05	1.0000-
04	LB/HR	1.8015-04	1.8015-04	1.8015-04	1.8015-04	1.8015-
06	CUFT/HR	2.9232-06	2.9234-06	2.9235-06	2.9237-06	2.9238-
	STATE VARIABLES:					
125.8752	TEMP F	124.8789	125.0987	125.3450	125.6061	
18.3000	PRES PSIA	17.9000	18.0000	18.1000	18.2000	
1.0000	VFRAC	0.0	0.0	0.0	0.0	0.0
	LFRAC	1.0000	1.0000	1.0000	1.0000	
	SFRAC	0.0	0.0	0.0	0.0	0.0
	ENTHALPY:					
1.2207+05	BTU/LBMOL	-1.2208+05	-1.2208+05	-1.2208+05	-1.2208+05	-
6776.0439	BTU/LB	-6776.5770	-6776.5038	-6776.3804	-6776.2236	-
1.2207	BTU/HR	-1.2208	-1.2208	-1.2208	-1.2208	-
	ENTROPY:					
37.4149	BTU/LBMOL-R	-37.4450	-37.4384	-37.4310	-37.4231	-
2.0768	BTU/LB-R	-2.0785	-2.0781	-2.0777	-2.0773	-
	DENSITY:					

LBMOL/CUFT	3.4209	3.4207	3.4206	3.4204	
3.4202					
LB/CUFT	61.6279	61.6256	61.6227	61.6192	
61.6155					
AVG MW	18.0153	18.0154	18.0154	18.0154	
18.0154					
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STREAM SECTION					
S16 S2 S3 S4 S5					
-----					
STREAM ID	S16	S2	S3	S4	S5
FROM :	STRIPPER	STRIPPER	STRIPPER	STRIPPER	
STRIPPER					
TO :	----	----	----	----	----
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	
LIQUID					
COMPONENTS: LBMOL/HR					
H2O	9.9992-06	9.9866-06	9.9899-06	9.9921-06	9.9936-
06					
H2S	9.2312-14	1.0797-14	1.1748-14	1.3606-14	1.6330-
14					
NH3	5.6618-10	1.2793-08	9.5574-09	7.4352-09	5.9143-
09					
N2	8.0143-11	6.6658-11	7.0696-11	7.3091-11	7.4628-
11					
O2	3.9121-11	3.1874-11	3.4173-11	3.5536-11	3.6399-
11					
H3O+	7.7092-17	1.7480-17	1.6086-17	1.6217-17	1.7231-
17					
NH4+	7.3428-11	2.3584-10	2.0642-10	1.8493-10	1.6828-
10					
HS-	4.6136-11	2.9741-11	3.2149-11	3.4997-11	3.8260-
11					
OH-	2.7290-11	2.0608-10	1.7425-10	1.4992-10	1.3001-
10					
S--	1.3582-15	8.3477-15	6.8521-15	6.0499-15	5.5468-
15					
COMPONENTS: LB/HR					
H2O	1.8014-04	1.7991-04	1.7997-04	1.8001-04	1.8004-
04					
H2S	3.1462-12	3.6797-13	4.0038-13	4.6373-13	5.5654-
13					
NH3	9.6423-09	2.1787-07	1.6277-07	1.2662-07	1.0072-
07					
N2	2.2451-09	1.8673-09	1.9805-09	2.0475-09	2.0906-
09					
O2	1.2518-09	1.0199-09	1.0935-09	1.1371-09	1.1647-
09					
H3O+	1.4665-15	3.3251-16	3.0599-16	3.0850-16	3.2778-
16					
NH4+	1.3245-09	4.2541-09	3.7234-09	3.3357-09	3.0354-
09					
HS-	1.5259-09	9.8367-10	1.0633-09	1.1575-09	1.2654-
09					
OH-	4.6414-10	3.5051-09	2.9637-09	2.5498-09	2.2112-
09					

S--	4.3554-14	2.6769-13	2.1973-13	1.9400-13	1.7787-
13					
TOTAL FLOW:					
LBMOL/HR	1.0000-05	1.0000-05	1.0000-05	1.0000-05	1.0000-
05					
LB/HR	1.8015-04	1.8014-04	1.8014-04	1.8015-04	1.8015-
04					
CUFT/HR	2.9240-06	2.9386-06	2.9314-06	2.9276-06	2.9255-
06					
STATE VARIABLES:					
TEMP F	126.1507	140.8701	133.1894	129.0372	
126.7526					
PRES PSIA	18.4000	17.0000	17.1000	17.2000	
17.3000					
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	
1.0000					
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.2207+05	-1.2170+05	-1.2186+05	-1.2196+05	-
1.2201+05					
BTU/LB	-6775.8457	-6755.5715	-6764.7157	-6769.8269	-
6772.7987					
BTU/HR	-1.2207	-1.2170	-1.2186	-1.2196	-
1.2201					
ENTROPY:					
BTU/LBMOL-R	-37.4066	-36.9570	-37.1890	-37.3158	-
37.3861					
BTU/LB-R	-2.0764	-2.0516	-2.0644	-2.0714	-
2.0753					
DENSITY:					
LBMOL/CUFT	3.4199	3.4030	3.4114	3.4158	
3.4183					
LB/CUFT	61.6112	61.3024	61.4542	61.5347	
61.5794					
AVG MW	18.0154	18.0142	18.0145	18.0147	
18.0149					

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STREAM SECTION

S6 S7 S8 S9 SOURWATR

STREAM ID	S6	S7	S8	S9	
SOURWATR					
FROM :	STRIPPER	STRIPPER	STRIPPER	STRIPPER	----
TO :	----	----	----	----	
STRIPPER					
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	
LIQUID					
COMPONENTS: LBMOL/HR					
H2O	9.9948-06	9.9957-06	9.9965-06	9.9971-06	
1383.4956					
H2S	2.0023-14	2.4858-14	3.1025-14	3.8670-14	2.2300-
06					
NH3	4.7632-09	3.8619-09	3.1414-09	2.5581-09	
4.3550					
N2	7.5680-11	7.6445-11	7.7040-11	7.7533-11	0.0
O2	3.6975-11	3.7381-11	3.7685-11	3.7928-11	0.0

09	H3O+	1.8919-17	2.1241-17	2.4231-17	2.7966-17	6.0758-
02	NH4+	1.5489-10	1.4385-10	1.3458-10	1.2662-10	4.8883-
03	HS-	4.1883-11	4.5759-11	4.9707-11	5.3462-11	3.6621-
02	OH-	1.1299-10	9.8083-11	8.4868-11	7.3152-11	4.5214-
06	S--	5.1775-15	4.8580-15	4.5408-15	4.1991-15	3.2583-
	COMPONENTS: LB/HR					
	H2O	1.8006-04	1.8008-04	1.8009-04	1.8010-04	
	2.4924+04					
	H2S	6.8241-13	8.4720-13	1.0574-12	1.3180-12	7.6004-
	NH3	8.1120-08	6.5771-08	5.3501-08	4.3566-08	
	74.1675					
	N2	2.1200-09	2.1415-09	2.1582-09	2.1720-09	0.0
	O2	1.1831-09	1.1961-09	1.2059-09	1.2136-09	0.0
	H3O+	3.5990-16	4.0405-16	4.6093-16	5.3200-16	1.1558-
	NH4+	2.7938-09	2.5948-09	2.4276-09	2.2840-09	
	0.8817					
	HS-	1.3853-09	1.5134-09	1.6440-09	1.7682-09	
	0.1211					
	OH-	1.9218-09	1.6682-09	1.4434-09	1.2442-09	
	0.7690					
	S--	1.6603-13	1.5578-13	1.4561-13	1.3465-13	1.0448-
	TOTAL FLOW:					
	LBMOL/HR	1.0000-05	1.0000-05	1.0000-05	1.0000-05	
	1387.9483					
	LB/HR	1.8015-04	1.8015-04	1.8015-04	1.8015-04	
	2.5000+04					
	CUFT/HR	2.9243-06	2.9236-06	2.9233-06	2.9232-06	
	415.4715					
	STATE VARIABLES:					
	TEMP F	125.5196	124.9002	124.6456	124.6097	
	190.0000					
	PRES PSIA	17.4000	17.5000	17.6000	17.7000	
	25.0000					
	VFRAC	0.0	0.0	0.0	0.0	0.0
	LFRAC	1.0000	1.0000	1.0000	1.0000	
	1.0000					
	SFRAC	0.0	0.0	0.0	0.0	0.0
	ENTHALPY:					
	BTU/LBMOL	-1.2204+05	-1.2206+05	-1.2207+05	-1.2208+05	-
	1.2065+05					
	BTU/LB	-6774.5514	-6775.5774	-6776.1567	-6776.4551	-
	6697.9781					
	BTU/HR	-1.2204	-1.2206	-1.2207	-1.2208	-
	1.6745+08					
	ENTROPY:					
	BTU/LBMOL-R	-37.4242	-37.4435	-37.4516	-37.4529	-
	35.5415					
	BTU/LB-R	-2.0774	-2.0785	-2.0789	-2.0790	-
	1.9732					
	DENSITY:					
	LBMOL/CUFT	3.4196	3.4204	3.4208	3.4209	
	3.3407					
	LB/CUFT	61.6046	61.6186	61.6257	61.6287	
	60.1726					
	AVG MW	18.0150	18.0151	18.0152	18.0152	
	18.0122					

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## PROBLEM STATUS SECTION

BLOCK STATUS  
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*****
**
*
*
* Calculations were completed normally
*
*
* All Unit Operation blocks were completed normally
*
*
* All streams were flashed normally
*
*
* All Convergence blocks were completed normally
*
*
*****
**
```

### A.5.3: Natural Gas Stripping Column Simulation without Acid

#### A.5.3.1: Input File

- This is an example of an ASPEN simulation that helped us optimize the stripping column. Since there is no one perfect simulation, the inputs and results from this simulation may not match the specifications, required outputs, or column sizing data; and this is expected. This specific run is for the 17-tray column with 25% Murphree Efficiency, Design Specified to reduce ammonia to 15 ppm (so that ammonia plus ammonium are together less than 20 ppm), for the maximum sour water flow rate and ammonia concentration.

```

;
;Input Summary created by Aspen Plus Rel. 36.0 at 04:06:59 Tue Apr 17,
2018
;Directory \\nestor\leconnor\CBE459 Filename
C:\Users\leconnor\AppData\Local\Temp\~ap484d.txt
;

DYNAMICS
  DYNAMICS RESULTS=ON

IN-UNITS ENG SHORT-LENGTH=in

DEF-STREAMS CONVEN ALL

MODEL-OPTION

DESCRIPTION "
  Electrolytes simulation with English Units :
  F, psi, lb/hr, lbmol/hr, Btu/hr, cuft/hr.

  Property Method: ELECRTL

  Flow basis for input: Mass

  Stream report composition: Mass flow
"

DATABANKS 'APV100 ASPENPCD' / 'APV100 AQUEOUS' / 'APV100 SOLIDS' &
  / 'APV100 INORGANIC' / 'APV100 PURE36'

PROP-SOURCES 'APV100 ASPENPCD' / 'APV100 AQUEOUS' / &
  'APV100 SOLIDS' / 'APV100 INORGANIC' / 'APV100 PURE36'

COMPONENTS
  H2O H2O /
  H2S H2S /
  NH3 H3N /
  N2 N2 /
  O2 O2 /
  H3O+ H3O+ /
  NH4+ NH4+ /
  HS- HS- /
  OH- OH- /
  S-- S-2 /
  CH4 CH4

```



```

HENRY-COMPS GLOBAL H2S NH3 O2 N2 CH4

SOLVE
  RUN-MODE MODE=SIM

CHEMISTRY GLOBAL
  PARAM GAMMA-BASIS=UNSYMMETRIC
  STOIC 1 NH3 -1 / H2O -1 / OH- 1 / NH4+ 1
  STOIC 2 H2O -1 / HS- -1 / H3O+ 1 / S-- 1
  STOIC 3 H2O -1 / H2S -1 / H3O+ 1 / HS- 1
  STOIC 4 H2O -2 / OH- 1 / H3O+ 1
  K-STOIC 1 A=-1.256563 B=-3335.699951 C=1.4971 D=-0.037057
  K-STOIC 2 A=-9.741963 B=-8585.469727 C=0 D=0
  K-STOIC 3 A=214.582443 B=-12995.400391 C=-33.5471 D=0
  K-STOIC 4 A=132.89888 B=-13445.900391 C=-22.477301 D=0

FLOWSHEET
  BLOCK STRIPPER IN=SOURWATR AIRFEED OUT=EXTRACT RAFINATE &
  S1

PROPERTIES ENRTL-RK HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL &
  TRUE-COMPS=NO
  PROPERTIES ELECNRTL

PROP-DATA HOCETA-1
  IN-UNITS ENG SHORT-LENGTH=in
  PROP-LIST HOCETA
  BPVAL H2O H2O 1.700000000
  BPVAL H2O H2S .7000000000
  BPVAL H2O NH3 .2000000000
  BPVAL H2S H2O .7000000000
  BPVAL H2S NH3 .1500000000
  BPVAL NH3 H2O .2000000000
  BPVAL NH3 H2S .1500000000

PROP-DATA HENRY-1
  IN-UNITS ENG PRESSURE=psi PDROP=psi SHORT-LENGTH=in
  PROP-LIST HENRY
  BPVAL H2S H2O 381.6601370 -23826.24000 -55.05510000 &
  .0330916666 31.73000000 301.7300000 0.0
  BPVAL NH3 H2O -158.8183807 -283.5936000 28.10010000 &
  -.0273483333 31.73000000 436.7300000 0.0
  BPVAL N2 H2O 180.3399883 -15178.98600 -21.55800000 &
  -4.6868000E-3 31.73000000 163.1300000 0.0
  BPVAL O2 H2O 157.8962298 -13995.10800 -18.39740000 &
  -5.2464111E-3 33.53000000 166.7300000 0.0
  BPVAL N2 NH3 10.80598441 0.0 0.0 0.0 67.73000000 &
  67.73000000 0.0
  BPVAL O2 NH3 11.20948341 0.0 0.0 0.0 67.73000000 &
  67.73000000 0.0
  BPVAL CH4 H2O 201.1724271 -16401.00600 -25.03790000 &
  7.96855556E-5 35.33000000 175.7300000 0.0

PROP-DATA NRTL-1
  IN-UNITS ENG SHORT-LENGTH=in
  PROP-LIST NRTL
  BPVAL H2O H2S -3.674000000 2080.620000 .2000000000 0.0 0.0 &
  0.0 32.00000000 302.0000000
  BPVAL H2S H2O -3.674000000 2080.620000 .2000000000 0.0 0.0 &
  0.0 32.00000000 302.0000000
  BPVAL H2O NH3 -.5440720000 3021.244200 .2000000000 0.0 0.0 &
  0.0 32.00000000 392.0000000
  BPVAL NH3 H2O -.1642422000 -1849.545000 .2000000000 0.0 &
  0.0 0.0 32.00000000 392.0000000

```

```
PROP-DATA GMELCC-1
IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMELCC
PPVAL H2O ( H3O+ HS- ) 8.045000000
PPVAL ( H3O+ HS- ) H2O -4.072000000
PPVAL H2O ( H3O+ OH- ) 8.045000000
PPVAL ( H3O+ OH- ) H2O -4.072000000
PPVAL H2O ( H3O+ S-- ) 8.045000000
PPVAL ( H3O+ S-- ) H2O -4.072000000
PPVAL H2O ( NH4+ HS- ) 8.060565000
PPVAL ( NH4+ HS- ) H2O -4.326618000
PPVAL H2O ( NH4+ OH- ) 8.045000000
PPVAL ( NH4+ OH- ) H2O -4.072000000
PPVAL H2O ( NH4+ S-- ) 8.045000000
PPVAL ( NH4+ S-- ) H2O -4.072000000
PPVAL H2S ( H3O+ HS- ) 15.000000000
PPVAL ( H3O+ HS- ) H2S -8.000000000
PPVAL H2S ( H3O+ OH- ) 15.000000000
PPVAL ( H3O+ OH- ) H2S -8.000000000
PPVAL H2S ( H3O+ S-- ) 15.000000000
PPVAL ( H3O+ S-- ) H2S -8.000000000
PPVAL H2S ( NH4+ HS- ) 10.000000000
PPVAL ( NH4+ HS- ) H2S -4.000000000
PPVAL NH3 ( NH4+ HS- ) 50.000000000
PPVAL ( NH4+ HS- ) NH3 -2.850924000
```

```
PROP-DATA GMELCD-1
IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMELCD
PPVAL H2O ( NH4+ HS- ) -85.25541600
PPVAL ( NH4+ HS- ) H2O 158.0140800
PPVAL H2S ( H3O+ HS- ) 0.0
PPVAL ( H3O+ HS- ) H2S 0.0
PPVAL H2S ( H3O+ OH- ) 0.0
PPVAL ( H3O+ OH- ) H2S 0.0
PPVAL H2S ( H3O+ S-- ) 0.0
PPVAL ( H3O+ S-- ) H2S 0.0
```

```
PROP-DATA GMELCE-1
IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMELCE
PPVAL H2S ( H3O+ HS- ) 0.0
PPVAL ( H3O+ HS- ) H2S 0.0
PPVAL H2S ( H3O+ OH- ) 0.0
PPVAL ( H3O+ OH- ) H2S 0.0
PPVAL H2S ( H3O+ S-- ) 0.0
PPVAL ( H3O+ S-- ) H2S 0.0
```

```
PROP-DATA GMELCN-1
IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMELCN
PPVAL H2S ( H3O+ HS- ) .1000000000
PPVAL H2S ( H3O+ OH- ) .1000000000
PPVAL H2S ( H3O+ S-- ) .1000000000
```

```
PROP-DATA GMENCC-1
IN-UNITS ENG SHORT-LENGTH=in
PROP-LIST GMENCC
PPVAL H2O ( H3O+ HS- ) 8.045000000
PPVAL ( H3O+ HS- ) H2O -4.072000000
PPVAL H2O ( H3O+ OH- ) 8.045000000
PPVAL ( H3O+ OH- ) H2O -4.072000000
PPVAL H2O ( H3O+ S-- ) 8.045000000
```

```

PPVAL ( H3O+ S-- ) H2O -4.072000000
PPVAL H2O ( NH4+ HS- ) 8.060565000
PPVAL ( NH4+ HS- ) H2O -4.326618000
PPVAL H2O ( NH4+ OH- ) 8.045000000
PPVAL ( NH4+ OH- ) H2O -4.072000000
PPVAL H2O ( NH4+ S-- ) 8.045000000
PPVAL ( NH4+ S-- ) H2O -4.072000000

PROP-DATA GMENCD-1
  IN-UNITS ENG SHORT-LENGTH=in
  PROP-LIST GMENCD
  PPVAL H2O ( NH4+ HS- ) -85.25541600
  PPVAL ( NH4+ HS- ) H2O 158.0140800

STREAM AIRFEED
  SUBSTREAM MIXED TEMP=190. PRES=35. MASS-FLOW=22347.
  MOLE-FRAC H2O 0.1 / CH4 0.9

STREAM SOURWATR
  SUBSTREAM MIXED TEMP=190. PRES=25. MASS-FLOW=25000.
  MASS-FRAC H2O 0.996995 / H2S 5E-006 / NH3 0.003

BLOCK STRIPPER RADFRAC
  SUBOBJECTS INTERNALS = CS-1
  PARAM NSTAGE=17 ALGORITHM=STANDARD EFF=MURPHREE ABSORBER=YES &
    HYDRAULIC=NO MAXOL=200 DAMPING=NONE
  PARAM2 STATIC-DP=YES
  COL-CONFIG CONDENSER=NONE REBOILER=NONE CA-CONFIG=INT-1
  FEEDS SOURWATR 1 / AIRFEED 17 ON-STAGE
  PRODUCTS RAFINATE 17 L / EXTRACT 1 V
  PSEUDO-STREA S1 1 MOLE-FLOW=1E-005
  P-SPEC 1 17.
  COL-SPECS DP-STAGE=0.1
  PROPERTIES ENRTL-RK HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL &
    FREE-WATER=STEAM-TA SOLU-WATER=3 TRUE-COMPS=YES
  REPORT NOHYDRAULIC
  STEFF-SEC SECNO=1 1 17 0.25
  INTERNALS CS-1 STAGE1=1 STAGE2=17 P-UPDATE=NO
  TRAY-SIZE 1 1 17 SIEVE

DESIGN-SPEC DS-1
  DEFINE NH3 MASS-FRAC STREAM=RAFINATE SUBSTREAM=MIXED &
    COMPONENT=NH3
  SPEC "NH3" TO "15e-06"
  TOL-SPEC ".1e-07"
  VARY STREAM-VAR STREAM=AIRFEED SUBSTREAM=MIXED &
    VARIABLE=MASS-FLOW UOM="lb/hr"
  LIMITS "8000" "45000"

EO-CONV-OPTI

CONV-OPTIONS
  PARAM TEAR-METHOD=BROYDEN TOL=0.001 SPEC-METHOD=BROYDEN

STREAM-REPOR MOLEFLOW MASSFLOW
;
;
;
;
;
;
;

```

### A.5.3.2: Output File

```

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          ASPEN PLUS CALCULATION REPORT
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          PLATFORM: WINDOWS                     APRIL 17, 2018
          VERSION: 36.0   Build 249             TUESDAY
          INSTALLATION:                        4:05:29 A.M.

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```

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RUN CONTROL SECTION

RUN CONTROL INFORMATION

THIS COPY OF ASPEN PLUS LICENSED TO UNIVERSITY OF PENNSYLVAN

TYPE OF RUN: NEW

INPUT FILE NAME: \_4249vil.inm

OUTPUT PROBLEM DATA FILE NAME: \_4249vil  
 LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:

NUMBER OF FILE RECORDS (PSIZE) = 0  
 NUMBER OF IN-CORE RECORDS = 256  
 PSIZE NEEDED FOR SIMULATION = 256

CALLING PROGRAM NAME: apmain  
 LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus v10.0\Engine\Xe

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

DESCRIPTION

Electrolytes simulation with English units : F, psi, lb/hr,  
 lbmol/hr, Btu/hr, cuft/hr. Property Method: ELECNRTL Flow basis  
 for input: Mass Stream report composition: Mass flow

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FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
AIRFEED	----	STRIPPER	SOURWATR	----	STRIPPER
EXTRACT	STRIPPER	----	RAFINATE	STRIPPER	----
S1	STRIPPER	----			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
STRIPPER	SOURWATR AIRFEED	EXTRACT RAFINATE S1

CONVERGENCE STATUS SUMMARY

-----  
DESIGN-SPEC SUMMARY  
=====

DESIGN SPEC	ERROR	TOLERANCE	ERR/TOL	VARIABLE	STAT	CONV BLOCK
DS-1	-0.64981E-08	0.10000E-07	-0.64981	18533.	#	

\$OLVER01

# = CONVERGED  
\* = NOT CONVERGED  
LB = AT LOWER BOUNDS  
UB = AT UPPER BOUNDS

DESIGN-SPEC: DS-1  
-----

SAMPLED VARIABLES:  
NH3 : NH3 MASSFRAC IN STREAM RAFINATE SUBSTREAM MIXED

SPECIFICATION:  
MAKE NH3 APPROACH 0.150000-04  
WITHIN 0.100000-07

MANIPULATED VARIABLES:  
VARY : TOTAL MASSFLOW IN STREAM AIRFEED SUBSTREAM MIXED  
LOWER LIMIT = 8,000.00 LB/HR  
UPPER LIMIT = 45,000.0 LB/HR  
FINAL VALUE = 18,532.9 LB/HR

VALUES OF ACCESSED FORTRAN VARIABLES:  
VARIABLE VALUE AT START OF LOOP FINAL VALUE UNITS  
-----  
NH3 0.505179E-05 0.149935E-04

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FLWSHEET SECTION

CONVERGENCE BLOCK: \$OLVER01  
-----

SPECS: DS-1  
MAXIT = 30  
PERTURBATION SIZE (% OF RANGE): DS-1 1.0000  
MAXIMUM STEP SIZE (% OF RANGE): DS-1 100.00  
METHOD: BROYDEN STATUS: CONVERGED  
TOTAL NUMBER OF ITERATIONS: 8

\*\*\* FINAL VALUES \*\*\*

VAR#	MANIPUL/TEAR-VAR	VARIABLE DESCRIPTION	UNIT
UNIT	VALUE	PREV VALUE	ERR/TOL
1	TOTAL MASSFLOW	AIRFEED.MIXED.TOTAL.MASSFLOW	LB/HR
1.8533+04	1.8568+04	-0.6498	

\*\*\* ITERATION HISTORY \*\*\*

DESIGN-SPEC ID: DS-1  
ITERATED: TOTAL MASSFLOW IN STREAM AIRFEED SUBSTREAM MIXED

ITERATION	VARIABLE	ERROR	ERR/TOL
1	0.2235E+05	-0.9948E-05	-994.8
2	0.2272E+05	-0.1045E-04	-1045.
3	0.1506E+05	0.2729E-04	2729.
4	0.2040E+05	-0.6196E-05	-619.6
5	0.1941E+05	-0.3336E-05	-333.6
6	0.1826E+05	0.1218E-05	121.8
7	0.1857E+05	-0.1574E-06	-15.74
8	0.1853E+05	-0.6498E-08	-0.6498

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:  
\$SOLVER01 STRIPPER  
(RETURN \$SOLVER01)

OVERALL FLOWSHEET BALANCE

DIFF.	CONVENTIONAL COMPONENTS (LBMOL/HR)	*** MASS AND ENERGY BALANCE IN	OUT	*** GENERATION	RELATIVE
0.910917E-14	H2O	1497.61	1497.66	0.428934E-01	-
0.439515E-13	H2S	0.223004E-05	0.203265E-02	0.203042E-02	
0.327019E-13	NH3	4.35497	4.39989	0.449271E-01	-
0.00000	N2	0.00000	0.00000	-0.810465E-12	
0.00000	O2	0.00000	0.00000	-0.490343E-06	
0.246183E-01	H3O+	0.607576E-08	0.222512E-07	0.167233E-07	
0.418241E-08	NH4+	0.488827E-01	0.395559E-02	-0.449271E-01	

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FLOWSHEET SECTION

OVERALL FLOWSHEET BALANCE (CONTINUED)

DIFF.	CONVENTIONAL COMPONENTS (LBMOL/HR)	*** MASS AND ENERGY BALANCE IN	OUT	*** GENERATION	RELATIVE
0.252063E-06	HS-	0.366215E-02	0.163495E-02	-0.202720E-02	-
0.108404E-04	OH-	0.452141E-01	0.232059E-02	-0.428930E-01	
0.115435E-03	S--	0.325827E-05	0.365875E-07	-0.322131E-05	

CH4	1027.07	1027.07	0.00000
0.135043E-13			
TOTAL BALANCE			
MOLE(LBMOL/HR)	2529.14	2529.14	-0.105151E-12
0.00000			
MASS(LB/HR )	43532.9	43532.9	-
0.501411E-15			
ENTHALPY(BTU/HR )	-0.211274E+09	-0.211274E+09	
0.228005E-07			

\*\*\* CO2 EQUIVALENT SUMMARY \*\*\*

FEED STREAMS CO2E	411925.	LB/HR
PRODUCT STREAMS CO2E	411925.	LB/HR
NET STREAMS CO2E PRODUCTION	0.00000	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR
TOTAL CO2E PRODUCTION	0.00000	LB/HR

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PHYSICAL PROPERTIES SECTION

COMPONENTS

ID	TYPE	ALIAS	NAME
H2O	C	H2O	WATER
H2S	C	H2S	HYDROGEN-SULFIDE
NH3	C	H3N	AMMONIA
N2	C	N2	NITROGEN
O2	C	O2	OXYGEN
H3O+	C	H3O+	H3O+
NH4+	C	NH4+	NH4+
HS-	C	HS-	HS-
OH-	C	OH-	OH-
S--	C	S-2	S--
CH4	C	CH4	METHANE

LISTID SUPERCRITICAL COMPONENT LIST  
GLOBAL H2S NH3 O2 N2 CH4

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC

INLETS	- SOURWATR	STAGE	1
	AIRFEED	STAGE	17
OUTLETS	- EXTRACT	STAGE	1
	RAFINATE	STAGE	17
	S1	STAGE	1
PROPERTY OPTION SET:	ENRTL-RK	ELECTROLYTE	NRTL / REDLICH-KWONG
HENRY-COMPS ID:	GLOBAL		
CHEMISTRY ID:	GLOBAL	- TRUE SPECIES	

\*\*\* MASS AND ENERGY BALANCE \*\*\*

DIFF.	IN	OUT	GENERATION	RELATIVE
TOTAL BALANCE				
MOLE(LBMOL/HR)	2529.14	2529.14		-0.105151E-12
0.179804E-15				



```

MASS(LB/HR )          43532.9      43532.9      -
0.334274E-15
ENTHALPY(BTU/HR )    -0.211274E+09 -0.211274E+09
0.228005E-07

*** CO2 EQUIVALENT SUMMARY ***
FEED STREAMS CO2E          411925.      LB/HR
PRODUCT STREAMS CO2E       411925.      LB/HR
NET STREAMS CO2E PRODUCTION 0.00000      LB/HR
UTILITIES CO2E PRODUCTION  0.00000      LB/HR
TOTAL CO2E PRODUCTION      0.00000      LB/HR

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                        U-O-S BLOCK SECTION

BLOCK:  STRIPPER MODEL: RADFRAC (CONTINUED)

                        *****
                        **** INPUT DATA ****
                        *****

**** INPUT PARAMETERS ****

NUMBER OF STAGES                17
ALGORITHM OPTION                STANDARD
INITIALIZATION OPTION          STANDARD
HYDRAULIC PARAMETER CALCULATIONS NO
INSIDE LOOP CONVERGENCE METHOD  NEWTON
DESIGN SPECIFICATION METHOD     NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS 200
MAXIMUM NO. OF INSIDE LOOP ITERATIONS  10
MAXIMUM NUMBER OF FLASH ITERATIONS    30
FLASH TOLERANCE                 0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE  0.000100000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST  1.00000
CONDENSER DUTY (W/O SUBCOOL)   BTU/HR  0.0
REBOILER DUTY                  BTU/HR  0.0

**** REAC-STAGES SPECIFICATIONS ****

STAGE TO STAGE          REACTIONS/CHEMISTRY ID
  1          17          GLOBAL

***** CHEMISTRY PARAGRAPH GLOBAL *****

**** REACTION PARAMETERS ****

RXN NO. TYPE          PHASE          CONC.          TEMP APP TO EQUIL
CONVERSION

  1  EQUILIBRIUM  LIQUID          BASIS          F
  2  EQUILIBRIUM  LIQUID          MOLE -GAMMA    0.0000
  3  EQUILIBRIUM  LIQUID          MOLE -GAMMA    0.0000
  4  EQUILIBRIUM  LIQUID          MOLE -GAMMA    0.0000

```

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

\*\* STOICHIOMETRIC COEFFICIENTS \*\*

RXN NO.	H2O	H2S	NH3	H3O+	NH4+
1	-1.000	0.000	-1.000	0.000	1.000
2	-1.000	0.000	0.000	1.000	0.000
3	-1.000	-1.000	0.000	1.000	0.000
4	-2.000	0.000	0.000	1.000	0.000

RXN NO.	HS-	OH-	S--	CH4
1	0.000	1.000	0.000	0.000
2	-1.000	0.000	1.000	0.000
3	1.000	0.000	0.000	0.000
4	0.000	1.000	0.000	0.000

\*\* COEFFICIENTS OF EQUILIBRIUM CONSTANT EXPRESSION \*\*

RXN NO.	A	B	C	D
E 1	-1.2566	-3335.7	1.4971	-0.37057E-01
0.0000 2	-9.7420	-8585.5	0.0000	0.0000
0.0000 3	214.58	-12995.	-33.547	0.0000
0.0000 4	132.90	-13446.	-22.477	0.0000

\*\*\*\* PROFILES \*\*\*\*

P-SPEC STAGE 1 PRES, PSIA 17.0000

\*\*\*\* TRAY MURPHREE EFFICIENCY \*\*\*\*

SEGMENT 1 17 EFFICIENCY 0.25000

\*\*\*\*\*  
\*\*\*\* RESULTS \*\*\*\*  
\*\*\*\*\*

\*\*\* COMPONENT SPLIT FRACTIONS \*\*\*

COMPONENT:	OUTLET STREAMS	
	EXTRACT	RAFINATE
H2O	.13354	.86646
H2S	.99680	.32049E-02
NH3	.99532	.46779E-02
H3O+	0.0000	1.0000
NH4+	0.0000	1.0000
HS-	0.0000	1.0000
OH-	0.0000	1.0000
S--	0.0000	1.0000
CH4	.99998	.22016E-04

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

\*\*\* SUMMARY OF KEY RESULTS \*\*\*

TOP STAGE TEMPERATURE	F	154.251
BOTTOM STAGE TEMPERATURE	F	138.841
TOP STAGE LIQUID FLOW	LBMOL/HR	1,346.79
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	1,297.71
TOP STAGE VAPOR FLOW	LBMOL/HR	1,231.42
BOILUP VAPOR FLOW	LBMOL/HR	1,158.08
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	0.0
REBOILER DUTY	BTU/HR	0.0

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

BUBBLE POINT	0.77011E-07	STAGE= 6
COMPONENT MASS BALANCE	0.20716E-12	STAGE= 1 COMP=H2S
ENERGY BALANCE	0.17551E-09	STAGE= 1

\*\*\*\* PROFILES \*\*\*\*

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

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL		HEAT DUTY BTU/HR
			LIQUID	VAPOR	
1	154.25	17.000	-0.12141E+06	-43165.	
2	139.43	17.100	-0.12173E+06	-41349.	
16	129.86	18.500	-0.12201E+06	-40027.	
17	138.84	18.600	-0.12185E+06	-39802.	

STAGE	FLOW RATE LBMOL/HR		FEED RATE LBMOL/HR			PRODUCT RATE LBMOL/HR
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID
VAPOR						
1	1347.	1231.	1387.9483			
2	1331.	1190.				
16	1315.	1161.				
17	1298.	1158.			1141.1867	1297.7139

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

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

STAGE	FLOW RATE LB/HR		FEED RATE LB/HR			PRODUCT RATE LB/HR
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID
VAPOR						
1	0.2426E+05	0.2015E+05	.25000+05			
	.20154+05					

2	0.2398E+05	0.1941E+05			
16	0.2368E+05	0.1889E+05			
17	0.2338E+05	0.1884E+05		.18533+05	.23379+05
**** MOLE-X-PROFILE ****					
STAGE	H2O	H2S	NH3	H3O+	NH4+
1	0.99813	0.11234E-08	0.17990E-02	0.21891E-11	
0.27660E-04					
2	0.99872	0.11246E-08	0.12133E-02	0.17231E-11	
0.23059E-04					
16	0.99995	0.60756E-08	0.25025E-04	0.11276E-10	
0.42085E-05					
17	0.99996	0.50200E-08	0.15860E-04	0.17146E-10	
0.30481E-05					
**** MOLE-X-PROFILE ****					
STAGE	HS-	OH-	S--	CH4	
1	0.28321E-05	0.24826E-04	0.11552E-08	0.13460E-04	
2	0.30925E-05	0.19964E-04	0.82409E-09	0.15726E-04	
16	0.21343E-05	0.20742E-05	0.49528E-10	0.18697E-04	
17	0.12599E-05	0.17882E-05	0.28194E-10	0.17424E-04	
**** MOLE-Y-PROFILE ****					
STAGE	H2O	H2S	NH3	H3O+	NH4+
1	0.16241	0.16454E-05	0.35563E-02	0.0000	0.0000
2	0.13507	0.18281E-05	0.20463E-02	0.0000	0.0000
16	0.11513	0.19064E-05	0.24793E-04	0.0000	0.0000
17	0.11311	0.10123E-05	0.11996E-04	0.0000	0.0000
**** MOLE-Y-PROFILE ****					
STAGE	HS-	OH-	S--	CH4	
1	0.0000	0.0000	0.0000	0.83403	
2	0.0000	0.0000	0.0000	0.86288	
16	0.0000	0.0000	0.0000	0.88484	
17	0.0000	0.0000	0.0000	0.88687	
**** K-VALUES ****					
STAGE	H2O	H2S	NH3	H3O+	NH4+
1	0.24489	976.75	4.4949	0.0000	0.0000
2	0.16825	875.59	3.3333	0.0000	0.0000
16	0.12119	755.25	2.5248	0.0000	0.0000
17	0.15246	806.60	3.0255	0.0000	0.0000
**** K-VALUES ****					
STAGE	HS-	OH-	S--	CH4	
1	0.0000	0.0000	0.0000	55535.	
2	0.0000	0.0000	0.0000	52645.	
16	0.0000	0.0000	0.0000	46999.	
17	0.0000	0.0000	0.0000	48638.	

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

**** RATES OF GENERATION ****					
	LBMOL/HR				
STAGE	H2O	H2S	NH3	H3O+	NH4+
HS-					
1	0.1178E-01	-.1505E-03	0.1163E-01	-.3127E-08	-.1163E-01
0.1522E-03					

2	0.6864E-02	-.3012E-03	0.6563E-02	-.6550E-09	-.6563E-02	
0.3016E-03						
16	0.3640E-03	0.1039E-02	0.1403E-02	0.2373E-08	-.1403E-02	-
.1039E-02						
17	0.4061E-03	0.1171E-02	0.1577E-02	0.7427E-08	-.1577E-02	-
.1171E-02						

\*\*\*\* RATES OF GENERATION \*\*\*\*  
LBMOL/HR

STAGE	OH-	S--	CH4
1	-.1178E-01	-.1702E-05	0.000
2	-.6864E-02	-.4590E-06	0.000
16	-.3640E-03	-.3389E-07	0.000
17	-.4061E-03	-.2852E-07	0.000

\*\*\*\* MASS-X-PROFILE \*\*\*\*

STAGE	H2O	H2S	NH3	H3O+	NH4+
1	0.99823	0.21255E-08	0.17008E-02	0.23118E-11	
0.27698E-04					
2	0.99879	0.21276E-08	0.11471E-02	0.18195E-11	
0.23089E-04					
16	0.99995	0.11494E-07	0.23657E-04	0.11907E-10	
0.42139E-05					
17	0.99996	0.94970E-08	0.14994E-04	0.18105E-10	
0.30520E-05					

\*\*\*\* MASS-X-PROFILE \*\*\*\*

STAGE	HS-	OH-	S--	CH4
1	0.52001E-05	0.23440E-04	0.20564E-08	0.11987E-04
2	0.56780E-05	0.18849E-04	0.14670E-08	0.14005E-04
16	0.39184E-05	0.19582E-05	0.88159E-10	0.16650E-04
17	0.23130E-05	0.16882E-05	0.50185E-10	0.15517E-04

\*\*\*\* MASS-Y-PROFILE \*\*\*\*

STAGE	H2O	H2S	NH3	H3O+	NH4+
1	0.17877	0.34263E-05	0.37006E-02	0.0000	0.0000
2	0.14918	0.38197E-05	0.21365E-02	0.0000	0.0000
16	0.12748	0.39934E-05	0.25952E-04	0.0000	0.0000
17	0.12528	0.21210E-05	0.12560E-04	0.0000	0.0000

\*\*\*\* MASS-Y-PROFILE \*\*\*\*

STAGE	HS-	OH-	S--	CH4
1	0.0000	0.0000	0.0000	0.81753
2	0.0000	0.0000	0.0000	0.84868
16	0.0000	0.0000	0.0000	0.87249
17	0.0000	0.0000	0.0000	0.87471

\*\*\*\* MURPHREE EFF \*\*\*\*

STAGE	H2O	H2S	NH3	H3O+	NH4+
1	0.25000	0.25000	0.25000	0.25000	0.25000
2	0.25000	0.25000	0.25000	0.25000	0.25000
16	0.25000	0.25000	0.25000	0.25000	0.25000
17	0.25000	0.25000	0.25000	0.25000	0.25000

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

\*\*\*\* MURPHREE EFF \*\*\*\*

STAGE	HS-	OH-	S--	CH4
1	0.25000	0.25000	0.25000	0.25000

2	0.25000	0.25000	0.25000	0.25000
16	0.25000	0.25000	0.25000	0.25000
17	0.25000	0.25000	0.25000	0.25000

\*\*\*\*\*  
\*\*\*\*\* HYDRAULIC PARAMETERS \*\*\*\*\*  
\*\*\*\*\*

\*\*\* DEFINITIONS \*\*\*

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

WHERE:

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

TEMPERATURE  
F

STAGE	LIQUID FROM	VAPOR TO
1	154.25	139.43
2	139.43	132.43
16	129.86	138.84
17	138.84	189.23

STAGE	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR
1	24260.	19415.	397.58	0.44645E+06	18.014	16.311
2	23976.	19130.	390.93	0.43281E+06	18.014	16.289
16	23683.	18837.	384.80	0.39894E+06	18.015	16.266
17	23379.	18533.	380.81	0.42650E+06	18.015	16.240

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

STAGE	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM	
	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	
1	61.021	0.43487E-01	0.41938	0.12591E-01	64.337	
2	61.330	0.44199E-01	0.47581	0.12445E-01	65.941	
16	61.546	0.47218E-01	0.51955	0.12541E-01	67.017	
17	61.392	0.43453E-01	0.47906	0.13407E-01	66.062	

MARANGONI INDEX      FLOW PARAM      QR      REDUCED F-FACTOR

STAGE	DYNE/CM		CUFT/HR	(LB-CUFT) **.5/HR
1		0.33359E-01	11923.	93100.
2	1.6038	0.33645E-01	11623.	90993.
16	-.19391	0.34824E-01	11054.	86688.
17	-.95503	0.33561E-01	11351.	88906.

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

\*\*\*\*\*  
 \*\*\* SECTION 1 \*\*\*  
 \*\*\*\*\*

STARTING STAGE NUMBER 1  
 ENDING STAGE NUMBER 17  
 FLOODING CALCULATION METHOD GLITSCH6

DESIGN PARAMETERS

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

TRAY SPECIFICATIONS

-----  
 TRAY TYPE SIEVE  
 NUMBER OF PASSES 1  
 TRAY SPACING FT 2.00000

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

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

STAGE WITH MAXIMUM DIAMETER 1  
 COLUMN DIAMETER FT 4.19142  
 DC AREA/COLUMN AREA 0.100000  
 DOWNCOMER VELOCITY FT/SEC 0.080040  
 FLOW PATH LENGTH FT 2.87971  
 SIDE DOWNCOMER WIDTH FT 0.65586  
 SIDE WEIR LENGTH FT 3.04553  
 CENTER DOWNCOMER WIDTH FT 0.0  
 CENTER WEIR LENGTH FT MISSING  
 OFF-CENTER DOWNCOMER WIDTH FT 0.0  
 OFF-CENTER SHORT WEIR LENGTH FT MISSING  
 OFF-CENTER LONG WEIR LENGTH FT MISSING  
 TRAY CENTER TO OCDC CENTER FT 0.0

\*\*\*\* SIZING PROFILES \*\*\*\*

STAGE	DIAMETER FT	TOTAL AREA SQFT	ACTIVE AREA SQFT	SIDE DC AREA SQFT
1	4.1914	13.798	11.038	1.3798
2	4.1914	13.798	11.038	1.3798
3	4.1914	13.798	11.038	1.3798
4	4.1914	13.798	11.038	1.3798
5	4.1914	13.798	11.038	1.3798
6	4.1914	13.798	11.038	1.3798
7	4.1914	13.798	11.038	1.3798
8	4.1914	13.798	11.038	1.3798
9	4.1914	13.798	11.038	1.3798
10	4.1914	13.798	11.038	1.3798
11	4.1914	13.798	11.038	1.3798
12	4.1914	13.798	11.038	1.3798
13	4.1914	13.798	11.038	1.3798
14	4.1914	13.798	11.038	1.3798
15	4.1914	13.798	11.038	1.3798
16	4.1914	13.798	11.038	1.3798
17	4.1914	13.798	11.038	1.3798

\*\*\*\* ADDITIONAL SIZING PROFILES \*\*\*\*

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
1	80.00	0.1466	0.6772	31.26
2	77.81	0.1426	0.6608	30.50
3	76.64	0.1405	0.6526	30.12
4	75.92	0.1392	0.6478	29.90
5	75.44	0.1384	0.6447	29.75
6	75.06	0.1377	0.6424	29.65
7	74.76	0.1372	0.6406	29.57
8	74.48	0.1367	0.6390	29.49
9	74.23	0.1363	0.6376	29.43
10	73.99	0.1359	0.6363	29.37
11	73.75	0.1355	0.6350	29.31
12	73.53	0.1351	0.6337	29.25
13	73.30	0.1347	0.6325	29.19
14	73.10	0.1343	0.6314	29.14

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U-O-S BLOCK SECTION

BLOCK: STRIPPER MODEL: RADFRAC (CONTINUED)

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
15	72.98	0.1341	0.6307	29.11
16	73.29	0.1345	0.6320	29.17
17	76.19	0.1384	0.6454	29.79

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
1	0.1718	0.6083	0.1749	36.81
2	0.1685	0.6083	0.1765	35.71
3	0.1669	0.6083	0.1774	35.15
4	0.1660	0.6083	0.1779	34.83
5	0.1655	0.6083	0.1783	34.62
6	0.1652	0.6083	0.1786	34.48



7	0.1650	0.6083	0.1789	34.36
8	0.1648	0.6083	0.1791	34.27
9	0.1647	0.6083	0.1793	34.18
10	0.1645	0.6083	0.1795	34.10
11	0.1644	0.6083	0.1797	34.02
12	0.1643	0.6083	0.1799	33.95
13	0.1642	0.6083	0.1801	33.87
14	0.1641	0.6083	0.1802	33.80
15	0.1640	0.6083	0.1803	33.77
16	0.1640	0.6083	0.1801	33.88
17	0.1640	0.6083	0.1782	34.86

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STREAM SECTION

AIRFEED EXTRACT RAFINATE S1 SOURWATR

STREAM ID	AIRFEED	EXTRACT	RAFINATE	S1	
SOURWATR					
FROM :	----	STRIPPER	STRIPPER	STRIPPER	----
TO :	STRIPPER	----	----	----	
STRIPPER					
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	LIQUID	LIQUID	
LIQUID					
COMPONENTS: LBMOL/HR					
H2O	114.1187	199.9943	1297.6628	9.9813-06	
1383.4956					
H2S	0.0	2.0261-03	6.5145-06	1.1234-14	2.2300-
06					
NH3	0.0	4.3793	2.0582-02	1.7990-08	
4.3550					
N2	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	2.2251-08	2.1891-17	6.0758-
09					
NH4+	0.0	0.0	3.9556-03	2.7660-10	4.8883-
02					
HS-	0.0	0.0	1.6349-03	2.8321-11	3.6621-
03					
OH-	0.0	0.0	2.3206-03	2.4826-10	4.5214-
02					
S--	0.0	0.0	3.6587-08	1.1552-14	3.2583-
06					
CH4	1027.0680	1027.0454	2.2612-02	1.3460-10	0.0
COMPONENTS: LB/HR					
H2O	2055.8798	3602.9536	2.3378+04	1.7982-04	
2.4924+04					
H2S	0.0	6.9055-02	2.2203-04	3.8288-13	7.6004-
05					
NH3	0.0	74.5821	0.3505	3.0638-07	
74.1675					
N2	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0
H3O+	0.0	0.0	4.2328-07	4.1643-16	1.1558-
07					
NH4+	0.0	0.0	7.1351-02	4.9894-09	
0.8817					
HS-	0.0	0.0	5.4075-02	9.3672-10	
0.1211					

OH-	0.0	0.0	3.9468-02	4.2224-09	
0.7690					
S--	0.0	0.0	1.1733-06	3.7044-13	1.0448-
04					
CH4	1.6477+04	1.6477+04	0.3628	2.1593-09	0.0
TOTAL FLOW:					
LBMOL/HR	1141.1867	1231.4211	1297.7140	1.0000-05	
1387.9483					
LB/HR	1.8533+04	2.0154+04	2.3379+04	1.8014-04	
2.5000+04					
CUFT/HR	2.2658+05	4.7609+05	380.8089	2.9520-06	
415.4715					
STATE VARIABLES:					
TEMP F	190.0000	154.2507	138.8412	154.2507	
190.0000					
PRES PSIA	35.0000	17.0000	18.6000	17.0000	
25.0000					
VFRAC	1.0000	1.0000	0.0	0.0	0.0
LFRAC	0.0	0.0	1.0000	1.0000	
1.0000					
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-3.8403+04	-4.3165+04	-1.2185+05	-1.2141+05	-
1.2065+05					
BTU/LB	-2364.7094	-2637.3452	-6763.4667	-6739.8708	-
6697.9781					
BTU/HR	-4.3825+07	-5.3154+07	-1.5812+08	-1.2141	-
1.6745+08					
ENTROPY:					
BTU/LBMOL-R	-17.7959	-16.0709	-37.0214	-36.5602	-
35.5415					
BTU/LB-R	-1.0958	-0.9819	-2.0550	-2.0296	-
1.9732					
DENSITY:					
LBMOL/CUFT	5.0366-03	2.5865-03	3.4078	3.3875	
3.3407					
LB/CUFT	8.1795-02	4.2332-02	61.3920	61.0205	
60.1726					
AVG MW	16.2400	16.3667	18.0152	18.0135	
18.0122					

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PROBLEM STATUS SECTION

BLOCK STATUS

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\*

\* calculations were completed normally

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\* All Unit Operation blocks were completed normally

\* \*

\*

\* All streams were flashed normally

\*

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*  
*  
* All Convergence blocks were completed normally  
*  
*  
*****  
**
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## A.6: Material Safety Data Sheets

### A.6.1: Hydrogen Sulfide



DELAWARE HEALTH  
AND SOCIAL SERVICES  
Division of Public Health

**Emergency  
Medical Services**

#### HYDROGEN SULFIDE

<b>Agent Information:</b>	Used in chemical synthesis, metallurgy and as a chemical warfare agent. H <sub>2</sub> S. Synonyms include dihydrogen sulfide, sulfur hydride, sulfured hydrogen, hydrosulfuric acid, "sewer gas," "swamp gas," hepatic acid, sour gas, and "stink damp." Hydrogen sulfide is a colorless, highly flammable and explosive gas produced naturally by decaying organic matter and by certain industrial processes. Hydrogen sulfide has a characteristic rotten-egg odor; however, olfactory fatigue may occur and may not provide adequate warning of hazardous concentrations. Hydrogen sulfide is slightly heavier than air and may accumulate in enclosed, poorly ventilated and low-lying areas. Hydrogen sulfides are toxicologically, part of a group of compounds known as systemic asphyxiants.
<b>Signs and Symptoms:</b>	Hydrogen sulfide is a mucous membrane and respiratory tract irritant; pulmonary edema, immediate or delayed, can occur after exposure to high concentrations. Breathing high levels of hydrogen sulfide can cause death within a few breaths, by way of respiratory arrest. Lower concentrations can result in eye irritation, sore throat and cough, shortness of breath, and fluid in the lungs. Symptoms of acute exposure include nausea, headaches, delirium, disturbed equilibrium, tremors, convulsions, and skin and eye irritation. Inhalation of high concentrations can produce extremely rapid unconsciousness and death. Exposure to the liquefied gas can cause frostbite injury.
<b>Route of Exposure:</b>	Inhalation is primary. Hydrogen sulfide is well absorbed through the lungs; cutaneous absorption is minimal. Exposure by any route can cause systemic effects.
<b>Protective Measures:</b>	Utilize appropriate Level PPE as identified by the Environmental Protection Agency and Hazmat protocols.  Only those directly exposed to hydrogen sulfide are at risk. Persons exposed to hydrogen sulfide pose no serious risks of secondary contamination to personnel outside the Hot Zone and after decontamination.
<b>Prophylaxis:</b>	N/A
<b>Treatment:</b>	Supportive care. Nitrite therapy (the cyanide antidote kit) has been suggested as a therapy for hydrogen sulfide exposure. Amyl nitrite is given by inhalation (for 30 seconds every minute until an intravenous line is established) followed by intravenous sodium nitrite (300 mg over absolutely no less than 5 minutes). It is not necessary to use the sodium thiosulfate. The antidotal efficacy of nitrite therapy is controversial, but is currently recommended if it can be started shortly after exposure.
<b>Reporting:</b>	Any suspect cases should be reported immediately to the Division of Public Health, Epidemiology Branch: 1-888-295-5156 (24/7 coverage). For additional information, view the CDC website for Emergency Preparedness and Response at <a href="http://www.bt.cdc.gov">www.bt.cdc.gov</a> .

**24/7 Emergency Contact Number: 1-888-295-5156**

Revised: 05/2007

Doc. # 35-05-20/07/05/60



# Right to Know Hazardous Substance Fact Sheet

Common Name: **HYDROGEN SULFIDE**

Synonyms: Dihydrogen Sulfide; Sulfurated Hydrogen; Sewer Gas  
Chemical Name: Hydrogen Sulfide  
Date: January 2000      Revision: May 2012

CAS Number: 7783-06-4  
RTK Substance Number: 1017  
DOT Number: UN 1053

### Description and Use

**Hydrogen Sulfide** is a colorless gas with the odor of rotten eggs. It is usually shipped as a liquid. **Hydrogen Sulfide** is found as a by-product of industrial and natural processes, and is used as a chemical reagent, in making heavy water, and is used in metallurgy, lubricants and cutting oils.

- ▶ **ODOR THRESHOLD = 0.008 to 0.1 ppm**  
(The odor of **Hydrogen Sulfide** can NOT be detected above **100 ppm**.)
- ▶ Odor thresholds vary greatly. Do not rely on odor alone to determine potentially hazardous exposures.

### Reasons for Citation

- ▶ **Hydrogen Sulfide** is on the Right to Know Hazardous Substance List because it is cited by OSHA, ACGIH, DOT, NIOSH, DEP, IRIS, NFPA and EPA.
- ▶ This chemical is on the Special Health Hazard Substance List.

SEE GLOSSARY ON PAGE 5.

### FIRST AID

#### Eye Contact

- ▶ Immediately flush with large amounts of water for at least 15 minutes, lifting upper and lower lids. Remove contact lenses, if worn, while flushing. Seek medical attention.

#### Skin Contact

- ▶ Immerse affected part in warm water. Seek medical attention.

#### Inhalation

- ▶ Remove the person from exposure.
- ▶ Begin rescue breathing (using universal precautions) if breathing has stopped and CPR if heart action has stopped.
- ▶ Transfer promptly to a medical facility.
- ▶ Medical observation is recommended for 24 to 48 hours after overexposure, as pulmonary edema may be delayed.

### EMERGENCY NUMBERS

Poison Control: 1-800-222-1222  
CHEMTREC: 1-800-424-9300  
NJDEP Hotline: 1-877-927-6337  
National Response Center: 1-800-424-8802

EMERGENCY RESPONDERS >>>> SEE LAST PAGE

### Hazard Summary

Hazard Rating	NJDOH	NFPA
HEALTH	-	4
FLAMMABILITY	-	4
REACTIVITY	-	0
FLAMMABLE POISONOUS GASES ARE PRODUCED IN FIRE CONTAINERS MAY EXPLODE IN FIRE		

Hazard Rating Key: 0=minimal; 1=slight; 2=moderate; 3=serious; 4=severe

- ▶ **Hydrogen Sulfide** can affect you when breathed in and may pass through your skin.
- ▶ **Hydrogen Sulfide** can irritate the eyes on contact. Long-term exposure to low levels can cause pain and redness of the eyes with blurred vision.
- ▶ Contact with the *liquid* may cause frostbite.
- ▶ Exposure to **Hydrogen Sulfide** can irritate the nose and throat.
- ▶ Inhaling **Hydrogen Sulfide** can irritate the lungs. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency.
- ▶ Exposure can cause nausea, dizziness, confusion, headache and trouble sleeping. Very high levels can cause unconsciousness and even death.
- ▶ **Hydrogen Sulfide** is a FLAMMABLE GAS and a DANGEROUS FIRE HAZARD.

### Workplace Exposure Limits

OSHA: The legal airborne permissible exposure limit (PEL) is **20 ppm** not to be exceeded at any time, and 50 ppm as a maximum peak, not to be exceeded during any 10-minute work period.

NIOSH: The recommended airborne exposure limit (REL) is **10 ppm**, which should not be exceeded during any 10-minute work period.

ACGIH: The threshold limit value (TLV) is **1 ppm** averaged over an 8-hour workshift and 5 ppm as a STEL (short-term exposure limit).

- ▶ The above exposure limits are for air levels only. When skin contact also occurs, you may be overexposed, even though air levels are less than the limits listed above.

## HYDROGEN SULFIDE

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## Determining Your Exposure

- ▶ Read the product manufacturer's Material Safety Data Sheet (MSDS) and the label to determine product ingredients and important safety and health information about the product mixture.
- ▶ For each individual hazardous ingredient, read the New Jersey Department of Health Hazardous Substance Fact Sheet, available on the RTK website ([www.nj.gov/health/eoh/rtkweb](http://www.nj.gov/health/eoh/rtkweb)) or in your facility's RTK Central File or Hazard Communication Standard file.
- ▶ You have a right to this information under the New Jersey Worker and Community Right to Know Act and the Public Employees Occupational Safety and Health (PEOSH) Act if you are a public worker in New Jersey, and under the federal Occupational Safety and Health Act (OSHA) if you are a private worker.
- ▶ The New Jersey Right to Know Act requires most employers to label chemicals in the workplace and requires public employers to provide their employees with information concerning chemical hazards and controls. The federal OSHA Hazard Communication Standard (29 CFR 1910.1200) and the PEOSH Hazard Communication Standard (N.J.A.C. 12:100-7) require employers to provide similar information and training to their employees.

This Fact Sheet is a summary of available information regarding the health hazards that may result from exposure. Duration of exposure, concentration of the substance and other factors will affect your susceptibility to any of the potential effects described below.

## Health Hazard Information

**Acute Health Effects**

The following acute (short-term) health effects may occur immediately or shortly after exposure to **Hydrogen Sulfide**:

- ▶ **Hydrogen Sulfide** can irritate the eyes on contact.
- ▶ Contact with the *liquid* may cause frostbite.
- ▶ Exposure to **Hydrogen Sulfide** can irritate the nose and throat.
- ▶ Inhaling **Hydrogen Sulfide** can irritate the lungs causing coughing and/or shortness of breath. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath.
- ▶ Exposure can cause nausea, dizziness, confusion, headache and trouble sleeping. Very high levels can cause unconsciousness and even death.

**Chronic Health Effects**

The following chronic (long-term) health effects can occur at some time after exposure to **Hydrogen Sulfide** and can last for months or years:

**Cancer Hazard**

- ▶ According to the information presently available to the New Jersey Department of Health, **Hydrogen Sulfide** has not been tested for its ability to cause cancer in animals.

**Reproductive Hazard**

- ▶ There is limited evidence that **Hydrogen Sulfide** causes spontaneous abortions.

**Other Effects**

- ▶ Long-term exposure to low levels can cause pain and redness of the eyes with blurred vision and lacrimation (flow of tears), and reduced sense of smell.
- ▶ **Hydrogen Sulfide** can irritate the lungs. Repeated exposure may cause bronchitis to develop with coughing, phlegm, and/or shortness of breath.

## Medical

**Medical Testing**

For frequent or potentially high exposure (half the TLV or greater), the following are recommended before beginning work and at regular times after that:

- ▶ Lung function tests

If symptoms develop or overexposure is suspected, the following is recommended:

- ▶ Consider chest x-ray after acute overexposure

Any evaluation should include a careful history of past and present symptoms with an exam. Medical tests that look for damage already done are not a substitute for controlling exposure.

Request copies of your medical testing. You have a legal right to this information under the OSHA Access to Employee Exposure and Medical Records Standard (29 CFR 1910.1020).

**Mixed Exposures**

- ▶ Smoking can cause heart disease, lung cancer, emphysema, and other respiratory problems. It may worsen respiratory conditions caused by chemical exposure. Even if you have smoked for a long time, stopping now will reduce your risk of developing health problems.

## HYDROGEN SULFIDE

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### Workplace Controls and Practices

Very toxic chemicals, or those that are reproductive hazards or sensitizers, require expert advice on control measures if a less toxic chemical cannot be substituted. Control measures include: (1) enclosing chemical processes for severely irritating and corrosive chemicals, (2) using local exhaust ventilation for chemicals that may be harmful with a single exposure, and (3) using general ventilation to control exposures to skin and eye irritants. For further information on workplace controls, consult the NIOSH document on Control Banding at [www.cdc.gov/niosh/topics/ctrlbanding/](http://www.cdc.gov/niosh/topics/ctrlbanding/).

The following work practices are also recommended:

- ▶ Label process containers.
- ▶ Provide employees with hazard information and training.
- ▶ Monitor airborne chemical concentrations.
- ▶ Use engineering controls if concentrations exceed recommended exposure levels.
- ▶ Provide eye wash fountains and emergency showers.
- ▶ Wash or shower if skin comes in contact with a hazardous material.
- ▶ Always wash at the end of the workshift.
- ▶ Change into clean clothing if clothing becomes contaminated.
- ▶ Do not take contaminated clothing home.
- ▶ Get special training to wash contaminated clothing.
- ▶ Do not eat, smoke, or drink in areas where chemicals are being handled, processed or stored.
- ▶ Wash hands carefully before eating, smoking, drinking, applying cosmetics or using the toilet.

In addition, the following may be useful or required:

- ▶ Specific actions are required for this chemical by OSHA. Refer to the OSHA *Compressed Gases* Standard (29 CFR 1910.101).
- ▶ Before entering a confined space where **Hydrogen Sulfide** may be present, check to make sure that an explosive concentration does not exist.
- ▶ Where possible, transfer **Hydrogen Sulfide** from cylinders or other containers to process containers in an enclosed system.

### Personal Protective Equipment

The OSHA Personal Protective Equipment Standard (29 CFR 1910.132) requires employers to determine the appropriate personal protective equipment for each hazard and to train employees on how and when to use protective equipment.

The following recommendations are only guidelines and may not apply to every situation.

#### Gloves and Clothing

- ▶ Avoid skin contact with **Hydrogen Sulfide**. Wear personal protective equipment made from material which can not be permeated or degraded by this substance. Safety equipment suppliers and manufacturers can provide recommendations on the most protective glove and clothing material for your operation.

- ▶ Safety equipment manufacturers recommend Neoprene, Viton and Barrier® as glove materials for *Inorganic gases* and *vapors*, and Tychem® BR, Responder® and TK, or the equivalent, as protective materials for clothing.
- ▶ Where exposure to cold equipment, vapors, or liquid may occur, employees should be provided with *insulated* gloves and special clothing designed to prevent the freezing of body tissues.
- ▶ All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

#### Eye Protection

- ▶ Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- ▶ If additional protection is needed for the entire face, use in combination with a face shield. A face shield should not be used without another type of eye protection.

#### Respiratory Protection

**Improper use of respirators is dangerous.** Respirators should only be used if the employer has implemented a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing, and medical exams, as described in the OSHA Respiratory Protection Standard (29 CFR 1910.134).

- ▶ Where the potential exists for exposure over **1 ppm**, use a NIOSH approved full facepiece powered-air purifying respirator with an acid gas cartridge which is specifically approved for **Hydrogen Sulfide**.
- ▶ Leave the area immediately if (1) while wearing a filter or cartridge respirator you can smell, taste, or otherwise detect **Hydrogen Sulfide**, (2) while wearing particulate filters abnormal resistance to breathing is experienced, or (3) eye irritation occurs while wearing a full facepiece respirator. Check to make sure the respirator-to-face seal is still good. If it is, replace the filter or cartridge. If the seal is no longer good, you may need a new respirator.
- ▶ Consider all potential sources of exposure in your workplace. You may need a combination of filters, prefilters or cartridges to protect against different forms of a chemical (such as vapor and mist) or against a mixture of chemicals.
- ▶ Where the potential exists for exposure over **10 ppm**, use a NIOSH approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode. For increased protection use in combination with an auxiliary self-contained breathing apparatus or an emergency escape air cylinder.
- ▶ Exposure to **100 ppm** is immediately dangerous to life and health. If the possibility of exposure above **100 ppm** exists, use a NIOSH approved self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode equipped with an emergency escape air cylinder.

## HYDROGEN SULFIDE

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### Fire Hazards

If employees are expected to fight fires, they must be trained and equipped as stated in the OSHA Fire Brigades Standard (29 CFR 1910.156).

- ▶ **Hydrogen Sulfide** is a **FLAMMABLE GAS**.
- ▶ Stop flow of gas and use water spray, dry chemical or CO<sub>2</sub> to extinguish fire.
- ▶ Use water spray to disperse vapors.
- ▶ **POISONOUS GASES ARE PRODUCED IN FIRE**, including *Sulfur Oxides*.
- ▶ **CONTAINERS MAY EXPLODE IN FIRE**.
- ▶ Use water spray to keep fire-exposed containers cool.
- ▶ Vapor is heavier than air and may travel a distance to cause a fire or explosion far from the source.
- ▶ Flow or agitation of **Hydrogen Sulfide** in *liquid* form may generate electrostatic charges.
- ▶ **Hydrogen Sulfide** may form an ignitable vapor/air mixture in closed tanks or containers.

### Spills and Emergencies

If employees are required to clean-up spills, they must be properly trained and equipped. The OSHA Hazardous Waste Operations and Emergency Response Standard (29 CFR 1910.120) may apply.

If **Hydrogen Sulfide** is leaked, take the following steps:

- ▶ Evacuate personnel and secure and control entrance to the area.
- ▶ Eliminate ignition sources.
- ▶ Ventilate area of leak to disperse the gas.
- ▶ Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty.
- ▶ Turn leaking cylinder with leak up to prevent escape of gas in liquid state.
- ▶ Keep **Hydrogen Sulfide** out of confined spaces, such as sewers, because of the possibility of an explosion.
- ▶ **DO NOT** wash into sewer.
- ▶ It may be necessary to contain and dispose of **Hydrogen Sulfide** as a **HAZARDOUS WASTE**. Contact your state Department of Environmental Protection (DEP) or your regional office of the federal Environmental Protection Agency (EPA) for specific recommendations.

### Handling and Storage

Prior to working with **Hydrogen Sulfide** you should be trained on its proper handling and storage.

- ▶ **Hydrogen Sulfide** reacts violently and/or explosively with **OXIDIZING AGENTS** (such as **PERCHLORATES**, **PEROXIDES**, **PERMANGANATES**, **CHLORATES**, **NITRATES**, **CHLORINE**, **BROMINE** and **FLUORINE**); **METALS**; **METAL POWDERS**; **METAL OXIDES**; and **STRONG NITRIC ACID**.
- ▶ **Hydrogen Sulfide** is not compatible with **STRONG BASES** (such as **SODIUM HYDROXIDE** and **POTASSIUM HYDROXIDE**).
- ▶ **Hydrogen Sulfide** may react with **RUSTY IRON PIPES** and some **PLASTICS**.

- ▶ Store in tightly closed containers in a cool, well-ventilated area away from **HEAT SOURCES** and **OXYGEN CYLINDERS**.
- ▶ Sources of ignition, such as smoking and open flames, are prohibited where **Hydrogen Sulfide** is used, handled, or stored.
- ▶ Metal containers involving the transfer of **Hydrogen Sulfide** should be grounded and bonded.
- ▶ Use explosion-proof electrical equipment and fittings wherever **Hydrogen Sulfide** is used, handled, manufactured, or stored.
- ▶ Use only non-sparking tools and equipment, especially when opening and closing containers of **Hydrogen Sulfide**.

### Occupational Health Information Resources

The New Jersey Department of Health offers multiple services in occupational health. These services include providing informational resources, educational materials, public presentations, and industrial hygiene and medical investigations and evaluations.

#### For more information, please contact:

New Jersey Department of Health  
Right to Know  
PO Box 368  
Trenton, NJ 08625-0368  
Phone: 609-984-2202  
Fax: 609-984-7407  
E-mail: [rtk@doh.state.nj.us](mailto:rtk@doh.state.nj.us)  
Web address: <http://www.nj.gov/health/eoh/rtkweb>

***The Right to Know Hazardous Substance Fact Sheets are not intended to be copied and sold for commercial purposes.***



## HYDROGEN SULFIDE

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## GLOSSARY

**ACGIH** is the American Conference of Governmental Industrial Hygienists. They publish guidelines called Threshold Limit Values (TLVs) for exposure to workplace chemicals.

**Acute Exposure Guideline Levels (AEGs)** are established by the EPA. They describe the risk to humans resulting from once-in-a-lifetime, or rare, exposure to airborne chemicals.

**Boiling point** is the temperature at which a substance can change its physical state from a liquid to a gas.

A **carcinogen** is a substance that causes cancer.

The **CAS number** is unique, identifying number, assigned by the Chemical Abstracts Service, to a specific chemical.

**CFR** is the Code of Federal Regulations, which are the regulations of the United States government.

A **combustible** substance is a solid, liquid or gas that will burn.

A **corrosive** substance is a gas, liquid or solid that causes destruction of human skin or severe corrosion of containers.

The **critical temperature** is the temperature above which a gas cannot be liquefied, regardless of the pressure applied.

**DEP** is the New Jersey Department of Environmental Protection.

**DOT** is the Department of Transportation, the federal agency that regulates the transportation of chemicals.

**EPA** is the Environmental Protection Agency, the federal agency responsible for regulating environmental hazards.

**ERG** is the Emergency Response Guidebook. It is a guide for emergency responders for transportation emergencies involving hazardous substances.

**Emergency Response Planning Guideline (ERPG)** values provide estimates of concentration ranges where one reasonably might anticipate observing adverse effects.

A **fetus** is an unborn human or animal.

A **flammable** substance is a solid, liquid, vapor or gas that will ignite easily and burn rapidly.

The **flash point** is the temperature at which a liquid or solid gives off vapor that can form a flammable mixture with air.

**IARC** is the International Agency for Research on Cancer, a scientific group.

**Ionization Potential** is the amount of energy needed to remove an electron from an atom or molecule. It is measured in electron volts.

**IRIS** is the Integrated Risk Information System database on human health effects that may result from exposure to various chemicals, maintained by federal EPA.

**LEL** or **Lower Explosive Limit**, is the lowest concentration of a combustible substance (gas or vapor) in the air capable of continuing an explosion.

**mg/m<sup>3</sup>** means milligrams of a chemical in a cubic meter of air. It is a measure of concentration (weight/volume).

A **mutagen** is a substance that causes mutations. A **mutation** is a change in the genetic material in a body cell. Mutations can lead to birth defects, miscarriages, or cancer.

**NFPA** is the National Fire Protection Association. It classifies substances according to their fire and explosion hazard.

**NIOSH** is the National Institute for Occupational Safety and Health. It tests equipment, evaluates and approves respirators, conducts studies of workplace hazards, and proposes standards to OSHA.

**NTP** is the National Toxicology Program which tests chemicals and reviews evidence for cancer.

**OSHA** is the federal Occupational Safety and Health Administration, which adopts and enforces health and safety standards.

**PEOSHA** is the New Jersey Public Employees Occupational Safety and Health Act, which adopts and enforces health and safety standards in public workplaces.

**Permeated** is the movement of chemicals through protective materials.

**ppm** means parts of a substance per million parts of air. It is a measure of concentration by volume in air.

**Protective Action Criteria (PAC)** are values established by the Department of Energy and are based on AEGs and ERPGs. They are used for emergency planning of chemical release events.

A **reactive** substance is a solid, liquid or gas that releases energy under certain conditions.

**STEL** is a Short Term Exposure Limit which is usually a 15-minute exposure that should not be exceeded at any time during a work day.

A **teratogen** is a substance that causes birth defects by damaging the fetus.

**UEL** or **Upper Explosive Limit** is the highest concentration in air above which there is too much fuel (gas or vapor) to begin a reaction or explosion.

**Vapor Density** is the ratio of the weight of a given volume of one gas to the weight of another (usually *Air*), at the same temperature and pressure.

The **vapor pressure** is a force exerted by the vapor in equilibrium with the solid or liquid phase of the same substance. The higher the vapor pressure the higher concentration of the substance in air.



Right to Know Hazardous Substance Fact Sheet

**Emergency  
Responders  
Quick Reference**

Common Name: **HYDROGEN SULFIDE**

Synonyms: Dihydrogen Sulfide; Sulfurated Hydrogen; Sewer Gas

CAS No: 7783-06-4

Molecular Formula: H<sub>2</sub>S

RTK Substance No: 1017

Description: Colorless gas with the odor of rotten eggs

HAZARD DATA	
<p><b>Hazard Rating</b></p> <p><b>4 - Health</b></p> <p><b>4 - Fire</b></p> <p><b>0 - Reactivity</b></p> <p><b>DOT#:</b> UN 1053</p> <p><b>ERG Guide #:</b> 117</p> <p><b>Hazard Class:</b> 2.3 (Poisonous)</p>	<p><b>Firefighting</b></p> <p>FLAMMABLE GAS</p> <p>Stop flow of gas and use water spray, dry chemical or CO<sub>2</sub> to extinguish fire.</p> <p>Use water spray to disperse vapors.</p> <p>POISONOUS GASES ARE PRODUCED IN FIRE, including <i>Sulfur Oxides</i>.</p> <p>CONTAINERS MAY EXPLODE IN FIRE.</p> <p>Use water spray to keep fire-exposed containers cool.</p> <p>Vapor is heavier than air and may travel a distance to cause a fire or explosion far from the source.</p> <p>Flow or agitation of <b>Hydrogen Sulfide</b> in <i>liquid</i> form may generate electrostatic charges.</p> <p><b>Hydrogen Sulfide</b> may form an ignitable vapor/air mixture in closed tanks or containers.</p>
<p><b>Reactivity</b></p> <p><b>Hydrogen Sulfide</b> reacts violently and/or explosively with OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE); METALS; METAL POWDERS; METAL OXIDES; and STRONG NITRIC ACID.</p> <p><b>Hydrogen Sulfide</b> is not compatible with STRONG BASES (such as SODIUM HYDROXIDE and POTASSIUM HYDROXIDE).</p> <p><b>Hydrogen Sulfide</b> may react with rusty iron pipes and some plastics.</p>	
SPILL/LEAKS	PHYSICAL PROPERTIES
<p><b>Isolation Distance:</b></p> <p>Small Spill: 30 meters (100 feet)</p> <p>Large Spill: 300 meters (1,000 feet)</p> <p>Fire: 800 meters (1/2 mile)</p> <p>Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty.</p> <p>Use only non-sparking tools and equipment, especially when opening and closing containers of <b>Hydrogen Sulfide</b>.</p> <p>Turn leaking cylinder with leak up to prevent escape of gas in liquid state.</p> <p>Keep <b>Hydrogen Sulfide</b> out of confined spaces, such as sewers, because of the possibility of an explosion.</p> <p>DO NOT wash into sewer.</p> <p>For water spills, neutralize with agricultural lime, crushed limestone or sodium bicarbonate.</p> <p><b>Hydrogen Sulfide</b> is very toxic to aquatic organisms.</p>	<p><b>Odor Threshold:</b> 0.008 to 0.1 ppm (&gt;100 ppm causes olfactory fatigue)</p> <p><b>Flash Point:</b> Flammable</p> <p><b>LEL:</b> 4%</p> <p><b>UEL:</b> 45%</p> <p><b>Auto Ignition Temp:</b> 500°F (260°C)</p> <p><b>Vapor Density:</b> 1.18 (air = 1)</p> <p><b>Vapor Pressure:</b> 14,000 mm Hg at 68°F (20°C)</p> <p><b>Specific Gravity:</b> 0.99 (water = 1)</p> <p><b>Water Solubility:</b> Soluble</p> <p><b>Boiling Point:</b> -76°F (-60°C)</p> <p><b>Freezing Point:</b> -122°F (-86°C)</p> <p><b>Ionization Potential:</b> 10.46 eV</p> <p><b>Molecular Weight:</b> 34.08</p>
EXPOSURE LIMITS	PROTECTIVE EQUIPMENT
<p><b>NIOSH:</b> 10 ppm, 10-min Ceiling</p> <p><b>ACGIH:</b> 1 ppm, 8-hr TWA; 5 ppm, STEL</p> <p><b>IDLH:</b> 100 ppm</p> <p>The Protective Action Criteria values are: PAC-1 = 0.51 ppm PAC-2 = 27 ppm PAC-3 = 50</p>	<p><b>Gloves:</b> <i>Insulated Neoprene, Viton and Barrier® (&gt;8-hr breakthrough for Inorganic gases and vapors)</i></p> <p><b>Coveralls:</b> Tychem® BR, Responder® and TK (&gt;8-hr breakthrough)</p> <p><b>Respirator:</b> &gt;1 ppm - full facepiece PAPR with cartridges specific for <b>Hydrogen Sulfide</b> &gt;10 ppm - SCBA</p>
HEALTH EFFECTS	FIRST AID AND DECONTAMINATION
<p><b>Eyes:</b> Irritation</p> <p><b>Skin:</b> Contact with liquid causes frostbite</p> <p><b>Inhalation:</b> Nose, throat and lung irritation, with coughing, and severe shortness of breath (pulmonary edema)</p> <p>Nausea, dizziness, headache, unconsciousness and even death</p>	<p><b>Remove</b> the person from exposure.</p> <p><b>Flush</b> eyes with large amounts of water for at least 15 minutes. Remove contact lenses if worn. Seek medical attention.</p> <p><b>Immerse</b> affected part in warm water. Seek medical attention.</p> <p><b>Begin</b> artificial respiration if breathing has stopped and CPR if necessary.</p> <p><b>Transfer</b> promptly to a medical facility. Medical observation is recommended as symptoms may be delayed.</p>

May 2012

## A.6.2: Ammonia



# Right to Know Hazardous Substance Fact Sheet

Common Name: **AMMONIA**

Synonyms: Anhydrous Ammonia

Chemical Name: Ammonia

Date: September 2007

Revision: February 2016

CAS Number: 7664-41-7

RTK Substance Number: 0084

DOT Number: UN 1005

### Description and Use

Ammonia is a colorless gas with a strong, sharp, irritating odor. It is often used in water solution. It is used in fertilizers, as a refrigerant, and in making plastics, dyes, textiles, detergents, and pesticides.

- ▶ **ODOR THRESHOLD = 5 ppm**
- ▶ Odor thresholds vary greatly. Do not rely on odor alone to determine potentially hazardous exposures.

### Reasons for Citation

- ▶ Ammonia is on the Right to Know Hazardous Substance List because it is cited by OSHA, ACGIH, DOT, NIOSH, DEP, NFPA and EPA.
- ▶ This chemical is on the Special Health Hazard Substance List.

SEE GLOSSARY ON PAGE 5.

### FIRST AID

#### Eye Contact

- ▶ Immediately flush with large amounts of water for at least 30 minutes, lifting upper and lower lids. Remove contact lenses, if worn, while flushing. Seek medical attention immediately.

#### Skin Contact

- ▶ Immerse affected part in warm water. Seek medical attention.

#### Inhalation

- ▶ Remove the person from exposure.
- ▶ Begin rescue breathing (using universal precautions) if breathing has stopped and CPR if heart action has stopped.
- ▶ Transfer promptly to a medical facility.
- ▶ Medical observation is recommended for 24 to 48 hours after overexposure, as pulmonary edema may be delayed.

### EMERGENCY NUMBERS

Poison Control: 1-800-222-1222

CHEMTREC: 1-800-424-9300

NJDEP Hotline: 1-877-927-6337

National Response Center: 1-800-424-8802

### EMERGENCY RESPONDERS >>>> SEE BACK PAGE

#### Hazard Summary

Hazard Rating	NJDHSS	NFPA
<b>HEALTH</b>	-	3
<b>FLAMMABILITY</b>	-	1
<b>REACTIVITY</b>	-	0
CORROSIVE MAY IGNITE AND BURN WITH EXPLOSIVE FORCE POISONOUS GASES ARE PRODUCED IN FIRE CONTAINERS MAY EXPLODE IN FIRE		

Hazard Rating Key: 0=minimal; 1=slight; 2=moderate; 3=serious; 4=severe

- ▶ Ammonia can affect you when inhaled.
- ▶ Contact can severely irritate and burn the skin and eyes with possible eye damage.
- ▶ Inhaling Ammonia can irritate the nose and throat.
- ▶ Inhaling Ammonia can irritate the lungs. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency.
- ▶ Repeated exposure may cause an asthma-like allergy and lead to lung damage.
- ▶ Contact with liquid Ammonia can cause frostbite.

### Workplace Exposure Limits

OSHA: The legal airborne permissible exposure limit (PEL) is **50 ppm** averaged over an 8-hour workshift.

NIOSH: The recommended airborne exposure limit (REL) is **25 ppm** averaged over a 10-hour workshift and **35 ppm**, not to be exceeded during any 15-minute work period.

ACGIH: The threshold limit value (TLV) is **25 ppm** averaged over an 8-hour workshift and **35 ppm** as a STEL (short-term exposure limit).

## AMMONIA

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**Determining Your Exposure**

- ▶ Read the product manufacturer's Material Safety Data Sheet (MSDS) and the label to determine product ingredients and important safety and health information about the product mixture.
- ▶ For each individual hazardous ingredient, read the New Jersey Department of Health Hazardous Substance Fact Sheet, available on the RTK website (<http://nj.gov/health/workplacehealthandsafety/right-to-know/>) or in your facility's RTK Central File or Hazard Communication Standard file.
- ▶ You have a right to this information under the New Jersey Worker and Community Right to Know Act, the Public Employees Occupational Safety and Health (PEOSH) Act if you are a public worker in New Jersey, and under the federal Occupational Safety and Health Act (OSHA) if you are a private worker.
- ▶ The New Jersey Right to Know Act requires most employers to label chemicals in the workplace and requires public employers to provide their employees with information concerning chemical hazards and controls. The federal OSHA Hazard Communication Standard (29 CFR 1910.1200) requires private employers to provide similar information and training to their employees.

This Fact Sheet is a summary of available information regarding the health hazards that may result from exposure. Duration of exposure, concentration of the substance and other factors will affect your susceptibility to any of the potential effects described below.

**Health Hazard Information****Acute Health Effects**

The following acute (short-term) health effects may occur immediately or shortly after exposure to **Ammonia**:

- ▶ Contact can severely irritate and burn the skin and eyes with possible eye damage.
- ▶ Inhaling **Ammonia** can irritate the nose and throat causing coughing and wheezing.
- ▶ Inhaling **Ammonia** can irritate the lungs causing coughing and/or shortness of breath. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath.
- ▶ Contact with *liquid Ammonia* can cause frostbite.

**Chronic Health Effects**

The following chronic (long-term) health effects can occur at some time after exposure to **Ammonia** and can last for months or years:

**Cancer Hazard**

- ▶ According to the information presently available to the New Jersey Department of Health, **Ammonia** has not been tested for its ability to cause cancer in animals.

**Reproductive Hazard**

- ▶ While **Ammonia** has been tested, it is not classifiable as to its potential to cause reproductive harm.

**Other Effects**

- ▶ **Ammonia** may cause an asthma-like allergy. Future exposure can cause asthma attacks with shortness of breath, wheezing, coughing, and/or chest tightness.
- ▶ Repeated exposure may lead to permanent lung damage.

**Medical****Medical Testing**

For frequent or potentially high exposure (half the TLV or greater), the following are recommended before beginning work and at regular times after that:

- ▶ Lung function tests. The results may be normal if the person is not having an attack at the time of the test.

If symptoms develop or overexposure is suspected, the following is recommended:

- ▶ Consider chest x-ray after acute overexposure

Any evaluation should include a careful history of past and present symptoms with an exam. Medical tests that look for damage already done are not a substitute for controlling exposure.

Request copies of your medical testing. You have a legal right to this information under the OSHA Access to Employee Exposure and Medical Records Standard (29 CFR 1910.1020).

**Mixed Exposures**

- ▶ Because smoking can cause heart disease, lung cancer, emphysema, and other respiratory problems, it may worsen respiratory conditions caused by chemical exposure. Even if you have smoked for a long time, stopping now will reduce your risk of developing health problems.

## AMMONIA

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### Workplace Controls and Practices

Very toxic chemicals, or those that are reproductive hazards or sensitizers, require expert advice on control measures if a less toxic chemical cannot be substituted. Control measures include: (1) enclosing chemical processes for severely irritating and corrosive chemicals, (2) using local exhaust ventilation for chemicals that may be harmful with a single exposure, and (3) using general ventilation to control exposures to skin and eye irritants. For further information on workplace controls, consult the NIOSH document on Control Banding at [www.cdc.gov/niosh/topics/ctrlbanding/](http://www.cdc.gov/niosh/topics/ctrlbanding/).

The following work practices are also recommended:

- ▶ Label process containers.
- ▶ Provide employees with hazard information and training.
- ▶ Monitor airborne chemical concentrations.
- ▶ Use engineering controls if concentrations exceed recommended exposure levels.
- ▶ Provide eye wash fountains and emergency showers.
- ▶ Wash or shower if skin comes in contact with a hazardous material.
- ▶ Always wash at the end of the workshift.
- ▶ Change into clean clothing if clothing becomes contaminated.
- ▶ Do not take contaminated clothing home.
- ▶ Get special training to wash contaminated clothing.
- ▶ Do not eat, smoke, or drink in areas where chemicals are being handled, processed or stored.
- ▶ Wash hands carefully before eating, smoking, drinking, applying cosmetics or using the toilet.

In addition, the following may be useful or required:

- ▶ Specific engineering controls are required for this chemical by OSHA. Refer to the OSHA *Compressed Gases* Standard (29 CFR 1910.101).

### Personal Protective Equipment

The OSHA Personal Protective Equipment Standard (29 CFR 1910.132) requires employers to determine the appropriate personal protective equipment for each hazard and to train employees on how and when to use protective equipment.

The following recommendations are only guidelines and may not apply to every situation.

#### Gloves and Clothing

- ▶ Avoid skin contact with **Ammonia**. Wear personal protective equipment made from material which can not be permeated or degraded by this substance. Safety equipment suppliers and manufacturers can provide recommendations on the most protective glove and clothing material for your operation.
- ▶ Safety equipment manufacturers recommend *Nitrile*, *Neoprene*, *Butyl*, *Butyl/Neoprene* or *Viton/ Neoprene* for gloves and Dupont *Tychem® CPE* and Kappler *Zytron® 500* as protective materials for clothing.
- ▶ Where exposure to cold equipment, vapors, or liquid may occur, employees should be provided with special clothing designed to prevent the freezing of body tissues.
- ▶ All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

#### Eye Protection

- ▶ Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- ▶ Wear a face shield along with goggles when working with corrosive, highly irritating or toxic substances.
- ▶ Do not wear contact lenses when working with this substance.

#### Respiratory Protection

**Improper use of respirators is dangerous.** Respirators should only be used if the employer has a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing, and medical exams, as described in the OSHA Respiratory Protection Standard (29 CFR 1910.134).

- ▶ Where the potential exists for exposure over **25 ppm**, use a NIOSH approved full facepiece respirator with a cartridge specifically approved for **Ammonia**. Increased protection is obtained from full facepiece powered-air purifying respirators.
- ▶ Leave the area immediately if (1) while wearing a filter or cartridge respirator you can smell, taste, or otherwise detect **Ammonia**, (2) while wearing particulate filters abnormal resistance to breathing is experienced, or (3) eye irritation occurs while wearing a full facepiece respirator. Check to make sure the respirator-to-face seal is still good. If it is, replace the filter or cartridge. If the seal is no longer good, you may need a new respirator.
- ▶ Consider all potential sources of exposure in your workplace. You may need a combination of filters, prefilters or cartridges to protect against different forms of a chemical (such as vapor and mist) or against a mixture of chemicals.
- ▶ Where the potential exists for exposure over **250 ppm**, use a NIOSH approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode. For increased protection use in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode.
- ▶ Exposure to **300 ppm** is immediately dangerous to life and health. If the possibility of exposure above **300 ppm** exists, use a NIOSH approved self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode equipped with an emergency escape air cylinder.

### Fire Hazards

If employees are expected to fight fires, they must be trained and equipped as stated in the OSHA Fire Brigades Standard (29 CFR 1910.156).

- ▶ Although **Ammonia** is not flammable, it MAY IGNITE AND BURN WITH EXPLOSIVE FORCE.
- ▶ Stop flow of gas or let burn.
- ▶ POISONOUS GASES ARE PRODUCED IN FIRE, including *Nitrogen Oxides*.
- ▶ CONTAINERS MAY EXPLODE IN FIRE.
- ▶ Use water spray to keep fire-exposed containers cool, and to absorb and disperse vapors.

**AMMONIA**

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**Spills and Emergencies**

If employees are required to clean-up spills, they must be properly trained and equipped. The OSHA Hazardous Waste Operations and Emergency Response Standard (29 CFR 1910.120) may apply.

If **Ammonia** is leaked, take the following steps:

- ▶ Evacuate personnel and secure and control entrance to the area.
- ▶ Ventilate area of leak to disperse the gas.
- ▶ Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty.
- ▶ Neutralize small *liquid* spills with *Hydrochloric acid*. Wipe with a mop or use water aspirators.
- ▶ Use water spray to keep cylinders or tanks cool. Move cylinders away from the fire if there is no risk.
- ▶ It may be necessary to contain and dispose of **Ammonia** as a **HAZARDOUS WASTE**. Contact your state Department of Environmental Protection (DEP) or your regional office of the federal Environmental Protection Agency (EPA) for specific recommendations.

**Handling and Storage**

Prior to working with **Ammonia** you should be trained on its proper handling and storage.

- ▶ **Ammonia** reacts violently with HALOGENS (such as FLUORINE, CHLORINE and BROMINE); ACIDS (such as HYDROGEN CHLORIDE, HYDROGEN FLUORIDE and HYDROGEN BROMIDE); NITROSYL CHLORIDE; CHROMYL CHLORIDE; TRIOXYGEN DICHLORIDE; NITROGEN DIOXIDE; NITROGEN TRICHLORIDE; BROMINE PENTAFLUORIDE; CHLORINE TRIFLUORIDE; and CALCIUM HYPOCHLORITE.
- ▶ Forms explosive compounds that are pressure and temperature sensitive with MERCURY; GOLD OXIDES; and SILVER SALTS and OXIDES.
- ▶ **Ammonia** is incompatible with CHLOROFORMATES; CYANIDES; OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES and NITRATES); DIMETHYL SULFATE; and MANY METALS and their ALLOYS (such as ZINC, COPPER and BRASS).
- ▶ **Ammonia** dissolves in WATER to release heat.
- ▶ Store in tightly closed containers in a cool, well-ventilated area away from HEAT, MOISTURE and DIRECT SUNLIGHT.

**Occupational Health Information Resources**

The New Jersey Department of Health and Occupational Health Service, offers multiple services in occupational health. These services include providing informational resources, educational materials, public presentations, and industrial hygiene and medical investigations and evaluations.

**For more information, please contact:**

New Jersey Department of Health  
Right to Know  
PO Box 368  
Trenton, NJ 08625-0368  
Phone: 609-984-2202  
Fax: 609-984-7407  
E-mail: [rtk@doh.nj.gov](mailto:rtk@doh.nj.gov)  
Web address:  
<http://nj.gov/health/workplacehealthandsafety/right-to-know/>

*The Right to Know Hazardous Substance Fact Sheets are not intended to be copied and sold for commercial purposes.*



**Right to Know Hazardous Substance Fact Sheet**

**Emergency  
Responders  
Quick Reference**

Common Name: **AMMONIA**

Synonyms: Anhydrous Ammonia

CAS No: 7664-41-7

Molecular Formula: NH<sub>3</sub>

RTK Substance No: 0084

Description: Colorless gas with a strong, sharp, irritating odor

HAZARD DATA	
<p><b>Hazard Rating</b></p> <p><b>3 - Health</b> <b>1 - Fire</b> <b>0 - Reactivity</b></p> <p>DOT#: UN 1005 ERG Guide #: 125 Hazard Class: 2.3 (Toxic Gases)</p>	<p><b>Firefighting</b></p> <p>Non-flammable gas which can ignite and burn with explosive force. Stop the flow of gas or let burn. POISONOUS GASES ARE PRODUCED IN FIRE, including <i>Nitrogen Oxides</i>. CONTAINERS MAY EXPLODE IN FIRE. Use water spray to keep fire-exposed containers cool, and to absorb and disperse vapors.</p>
<p><b>Reactivity</b></p> <p><b>Ammonia</b> reacts violently with HALOGENS (such as FLUORINE, CHLORINE and BROMINE); ACIDS (such as HYDROGEN CHLORIDE, HYDROGEN FLUORIDE and HYDROGEN BROMIDE); NITROSYL CHLORIDE; CHROMYL CHLORIDE; TRIOXYGEN DICHLORIDE; NITROGEN DIOXIDE; NITROGEN TRICHLORIDE; BROMINE PENTAFLUORIDE; CHLORINE TRIFLUORIDE; CALCIUM HYPOCHLORITE; and forms explosive compounds that are pressure and temperature sensitive with MERCURY; GOLD OXIDES; and SILVER SALTS and OXIDES. <b>Ammonia</b> is incompatible with CHLOROFORMATES; CYANIDES; OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES and NITRATES); DIMETHYL SULFATE; and MANY METALS and their ALLOYS (such as ZINC, COPPER and BRASS). <b>Ammonia</b> dissolves in WATER to release heat. Keep away from HEAT, MOISTURE and DIRECT SUNLIGHT.</p>	
SPILL/LEAKS	PHYSICAL PROPERTIES
<p><b>Isolation Distance:</b></p> <p>Small spills – 30 meters (100 feet) Large spills – 60 meters (200 feet) Stop flow of gas. Use water spray to absorb and disperse vapors. Hazardous to the environment. DO NOT wash into sewer.</p>	<p><b>Odor Threshold:</b> Less than 5 ppm <b>Flash Point:</b> Non-flammable <b>LEL:</b> 15% <b>UEL:</b> 28% <b>Vapor Density:</b> 0.6 (air = 1) <b>Vapor Pressure:</b> 658 mm of Hg at 70°F (21°C) <b>Water Solubility:</b> Soluble <b>Boiling Point:</b> -28°F (-33.4°C) <b>Ionization Potential:</b> 10.18 eV <b>Autoignition:</b> 1,204°F (651°C)</p>
EXPOSURE LIMITS	PROTECTIVE EQUIPMENT
<p><b>OSHA:</b> 50 ppm (8-hr TWA) <b>NIOSH:</b> 25 ppm (10-hr TWA), 35 ppm STEL <b>ACGIH:</b> 25 ppm (8-hr TWA), 35 ppm STEL <b>IDLH LEVEL:</b> 300 ppm <b>ERPG-1:</b> 25 ppm <b>ERPG-2:</b> 150 ppm <b>ERPG-3:</b> 1,500 ppm</p>	<p><b>Gloves:</b> Nitrile, Neoprene, Butyl, Butyl/Neoprene, Viton/Neoprene <b>Coveralls:</b> Dupont Tychem® CPE and Kappler Zytron® 500 <b>Boots:</b> Butyl/Neoprene <b>Respirator:</b> &gt; 25 ppm - APR with full-facepiece and cartridges for <b>Ammonia</b> &gt;250 ppm - Supplied Air &gt;300 ppm - SCBA</p>
HEALTH EFFECTS	FIRST AID AND DECONTAMINATION
<p><b>Eyes:</b> Irritation and burns <b>Skin:</b> Irritation and burns. Contact with liquid causes frostbite. <b>Acute:</b> Nose, throat and lung irritation with coughing and shortness of breath <b>Chronic:</b> An asthma-like allergy with shortness of breath, wheezing, coughing and/or chest tightness</p>	<p><b>Remove</b> the person from exposure. <b>Flush</b> eyes with large amounts of water for at least 30 minutes. Remove contact lenses if worn. Seek medical attention immediately. <b>Immerse</b> affected part in warm water if in contact with liquid. <b>Begin</b> artificial respiration if breathing has stopped and CPR if necessary. <b>Transfer</b> to a medical facility.</p>

February 2016

### A.6.3: Sulfuric Acid



## Right to Know Hazardous Substance Fact Sheet

Common Name: **SULFURIC ACID**

Synonyms: Battery Acid; Hydrogen Sulfate; Oil of Vitriol

Chemical Name: Sulfuric Acid

Date: December 2008

Revision: March 2016

CAS Number: 7664-93-9

RTK Substance Number: 1761

DOT Number: UN 1830

#### Description and Use

**Sulfuric Acid** is a clear, colorless to brown, odorless liquid. It is used to make storage batteries, fertilizers, paper products, textiles, explosives, and pharmaceuticals, and in steel and iron production.

#### Reasons for Citation

- ▶ **Sulfuric Acid** is on the Right to Know Hazardous Substance List because it is cited by OSHA, ACGIH, DOT, NIOSH, NTP, DEP, IARC, NFPA and EPA.
- ▶ This chemical is on the Special Health Hazard Substance List.

SEE GLOSSARY ON PAGE 5.

#### FIRST AID

##### Eye Contact

- ▶ Immediately flush with large amounts of water for at least 30 minutes, lifting upper and lower lids. Remove contact lenses, if worn, while flushing. Seek medical attention immediately.

##### Skin Contact

- ▶ Quickly remove contaminated clothing. Immediately wash contaminated skin with large amounts of soap and water. Seek medical attention immediately.

##### Inhalation

- ▶ Remove the person from exposure.
- ▶ Begin rescue breathing (using universal precautions) if breathing has stopped and CPR if heart action has stopped.
- ▶ Transfer promptly to a medical facility.
- ▶ Medical observation is recommended for 24 to 48 hours after overexposure, as pulmonary edema may be delayed.

#### EMERGENCY NUMBERS

**Poison Control: 1-800-222-1222**

**CHEMTREC: 1-800-424-9300**

**NJDEP Hotline: 1-877-927-6337**

**National Response Center: 1-800-424-8802**

#### EMERGENCY RESPONDERS >>>> SEE BACK PAGE

##### Hazard Summary

Hazard Rating	NJDHSS	NFPA
<b>HEALTH</b>	-	3
<b>FLAMMABILITY</b>	-	0
<b>REACTIVITY</b>	-	2-4

CARCINOGEN  
CORROSIVE AND REACTIVE  
OXIDIZER  
POISONOUS GASES ARE PRODUCED IN FIRE  
CONTAINERS MAY EXPLODE IN FIRE  
DO NOT USE WATER

*Hazard Rating Key: 0=minimal; 1=slight; 2=moderate; 3=serious; 4=severe*

- ▶ **Sulfuric Acid** can affect you when inhaled.
- ▶ **Sulfuric Acid** is a CARCINOGEN. HANDLE WITH EXTREME CAUTION.
- ▶ **Sulfuric Acid** is CORROSIVE and contact can severely irritate and burn the skin and eyes, and may lead to blindness.
- ▶ Inhaling **Sulfuric Acid** can irritate the nose and throat.
- ▶ Inhaling **Sulfuric Acid** can irritate the lungs. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency.
- ▶ Exposure can cause headache, nausea and vomiting.
- ▶ Repeated exposure can cause permanent lung damage, damage to teeth, and upset stomach.
- ▶ **Sulfuric Acid** is REACTIVE and a DANGEROUS EXPLOSION HAZARD.
- ▶ **Sulfuric Acid** is not combustible, but it is a STRONG OXIDIZER that enhances the combustion of other substances.

#### Workplace Exposure Limits

OSHA: The legal airborne permissible exposure limit (PEL) is **1 mg/m<sup>3</sup>** averaged over an 8-hour workshift.

NIOSH: The recommended airborne exposure limit (REL) is **1 mg/m<sup>3</sup>** averaged over a 10-hour workshift.

ACGIH: The threshold limit value (TLV) is **0.2 mg/m<sup>3</sup>** (as the *Thoracic fraction*) averaged over an 8-hour workshift.

- ▶ **Sulfuric Acid** is a CARCINOGEN in humans. There may be no safe level of exposure to a carcinogen, so all contact should be reduced to the lowest possible level.



## SULFURIC ACID

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**Determining Your Exposure**

- ▶ Read the product manufacturer's Material Safety Data Sheet (MSDS) and the label to determine product ingredients and important safety and health information about the product mixture.
- ▶ For each individual hazardous ingredient, read the New Jersey Department of Health Hazardous Substance Fact Sheet, available on the RTK website (<http://nj.gov/health/workplacehealthandsafety/right-to-know>) or in your facility's RTK Central File or Hazard Communication Standard file.
- ▶ You have a right to this information under the New Jersey Worker and Community Right to Know Act, the Public Employees Occupational Safety and Health (PEOSH) Act if you are a public worker in New Jersey, and under the federal Occupational Safety and Health Act (OSHA) if you are a private worker.
- ▶ The New Jersey Right to Know Act requires most employers to label chemicals in the workplace and requires public employers to provide their employees with information concerning chemical hazards and controls. The federal OSHA Hazard Communication Standard (29 CFR 1910.1200) and the PEOSH Hazard Communication Standard (N.J.A.C. 12:100-7) require employers to provide similar information and training to their employees.

This Fact Sheet is a summary of available information regarding the health hazards that may result from exposure. Duration of exposure, concentration of the substance and other factors will affect your susceptibility to any of the potential effects described below.

**Health Hazard Information****Acute Health Effects**

The following acute (short-term) health effects may occur immediately or shortly after exposure to **Sulfuric Acid**:

- ▶ Contact can severely irritate and burn the skin and eyes, and may lead to blindness.
- ▶ Inhaling **Sulfuric Acid** can irritate the nose and throat.
- ▶ Inhaling **Sulfuric Acid** can irritate the lungs causing coughing and/or shortness of breath. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath.
- ▶ Exposure can cause headache, nausea and vomiting.

**Chronic Health Effects**

The following chronic (long-term) health effects can occur at some time after exposure to **Sulfuric Acid** and can last for months or years:

**Cancer Hazard**

- ▶ **Sulfuric Acid** is a CARCINOGEN in humans. There is evidence that occupational exposure to *strong inorganic acid mists* containing **Sulfuric Acid** cause cancer of the larynx in humans.
- ▶ Many scientists believe there is no safe level of exposure to a carcinogen.

**Reproductive Hazard**

- ▶ While **Sulfuric Acid** has been tested, further testing is required to assess its potential to cause reproductive harm.

**Other Effects**

- ▶ **Sulfuric Acid** can irritate the lungs. Repeated exposure may cause bronchitis to develop with coughing, phlegm, and/or shortness of breath.
- ▶ Repeated exposure can cause permanent lung damage, damage to teeth, and upset stomach.

**Medical****Medical Testing**

Before beginning employment and at regular times thereafter, (at least annually), the following are recommended:

- ▶ Lung function tests

If symptoms develop or overexposure is suspected, the following is recommended:

- ▶ Consider chest x-ray after acute overexposure

Any evaluation should include a careful history of past and present symptoms with an exam. Medical tests that look for damage already done are not a substitute for controlling exposure.

Request copies of your medical testing. You have a legal right to this information under the OSHA Access to Employee Exposure and Medical Records Standard (29 CFR 1910.1020).

**Mixed Exposures**

- ▶ Smoking can cause heart disease, lung cancer, emphysema, and other respiratory problems. It may worsen respiratory conditions caused by chemical exposure. Even if you have smoked for a long time, stopping now will reduce your risk of developing health problems.

## SULFURIC ACID

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### Workplace Controls and Practices

Very toxic chemicals, or those that are reproductive hazards or sensitizers, require expert advice on control measures if a less toxic chemical cannot be substituted. Control measures include: (1) enclosing chemical processes for severely irritating and corrosive chemicals, (2) using local exhaust ventilation for chemicals that may be harmful with a single exposure, and (3) using general ventilation to control exposures to skin and eye irritants. For further information on workplace controls, consult the NIOSH document on Control Banding at [www.cdc.gov/niosh/topics/ctrlbanding/](http://www.cdc.gov/niosh/topics/ctrlbanding/).

The following work practices are also recommended:

- ▶ Label process containers.
- ▶ Provide employees with hazard information and training.
- ▶ Monitor airborne chemical concentrations.
- ▶ Use engineering controls if concentrations exceed recommended exposure levels.
- ▶ Provide eye wash fountains and emergency showers.
- ▶ Wash or shower if skin comes in contact with a hazardous material.
- ▶ Always wash at the end of the workshift.
- ▶ Change into clean clothing if clothing becomes contaminated.
- ▶ Do not take contaminated clothing home.
- ▶ Get special training to wash contaminated clothing.
- ▶ Do not eat, smoke, or drink in areas where chemicals are being handled, processed or stored.
- ▶ Wash hands carefully before eating, smoking, drinking, applying cosmetics or using the toilet.

In addition, the following may be useful or required:

- ▶ Before entering a confined space where **Sulfuric Acid** may be present, check to make sure that an explosive concentration does not exist.
- ▶ Where possible, transfer **Sulfuric Acid** from drums or other containers to process containers in an enclosed system.

### Personal Protective Equipment

The OSHA Personal Protective Equipment Standard (29 CFR 1910.132) requires employers to determine the appropriate personal protective equipment for each hazard and to train employees on how and when to use protective equipment.

The following recommendations are only guidelines and may not apply to every situation.

#### Gloves and Clothing

- ▶ Avoid skin contact with **Sulfuric Acid**. Wear personal protective equipment made from material which can not be permeated or degraded by this substance. Safety equipment suppliers and manufacturers can provide recommendations on the most protective glove and clothing material for your operation.
- ▶ Safety equipment manufacturers recommend Butyl, Silver Shield®4H®, Viton and Barrier® for gloves, and Tychem® fabrics; Zyttron® 300; ONESuit®TEC; and Trelchem® HPS and VPS, or the equivalent, as protective materials for clothing.
- ▶ All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

#### Eye Protection

- ▶ Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- ▶ Wear indirect-vent, impact and splash resistant goggles when working with liquids.
- ▶ Wear a face shield along with goggles when working with corrosive, highly irritating or toxic substances.

#### Respiratory Protection

**Improper use of respirators is dangerous.** Respirators should only be used if the employer has implemented a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing, and medical exams, as described in the OSHA Respiratory Protection Standard (29 CFR 1910.134).

- ▶ Where the potential exists for exposure over **0.2 mg/m<sup>3</sup>**, use a NIOSH approved full facepiece respirator with an acid gas cartridge specifically approved for **Sulfuric Acid**, with an R or P100 prefilter. Increased protection is obtained from full facepiece powered-air purifying respirators.
- ▶ Leave the area immediately if (1) while wearing a filter or cartridge respirator you can smell, taste, or otherwise detect **Sulfuric Acid**, (2) while wearing particulate filters abnormal resistance to breathing is experienced, or (3) eye irritation occurs while wearing a full facepiece respirator. Check to make sure the respirator-to-face seal is still good. If it is, replace the filter or cartridge. If the seal is no longer good, you may need a new respirator.
- ▶ Consider all potential sources of exposure in your workplace. You may need a combination of filters, prefilters or cartridges to protect against different forms of a chemical (such as vapor and mist) or against a mixture of chemicals.
- ▶ Where the potential exists for exposure over **2 mg/m<sup>3</sup>**, use a NIOSH approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode. For increased protection use in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode.
- ▶ Exposure to **15 mg/m<sup>3</sup>** is immediately dangerous to life and health. If the possibility of exposure above **15 mg/m<sup>3</sup>** exists, use a NIOSH approved self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode equipped with an emergency escape air cylinder.

### Fire Hazards

If employees are expected to fight fires, they must be trained and equipped as stated in the OSHA Fire Brigades Standard (29 CFR 1910.156).

- ▶ **Sulfuric Acid** is not combustible, but it is a STRONG OXIDIZER that enhances the combustion of other substances.
- ▶ Extinguish fire using an agent suitable for type of surrounding fire. **Sulfuric Acid** itself does not burn.
- ▶ DO NOT USE WATER directly on **Sulfuric Acid**.
- ▶ POISONOUS GASES ARE PRODUCED IN FIRE, including *Sulfur Oxides*.
- ▶ CONTAINERS MAY EXPLODE IN FIRE.
- ▶ **Sulfuric Acid** may ignite combustibles (wood, paper, and oil).

## SULFURIC ACID

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### Spills and Emergencies

If employees are required to clean-up spills, they must be properly trained and equipped. The OSHA Hazardous Waste Operations and Emergency Response Standard (29 CFR 1910.120) may apply.

If **Sulfuric Acid** is spilled or leaked, take the following steps:

- ▶ Evacuate personnel and secure and control entrance to the area.
- ▶ Eliminate all ignition sources.
- ▶ Neutralize spill with crushed limestone, soda ash or lime and place into sealed containers for disposal.
- ▶ DO NOT USE WATER OR WET METHOD.
- ▶ Ventilate area of spill or leak.
- ▶ DO NOT wash into sewer.
- ▶ It may be necessary to contain and dispose of **Sulfuric Acid** as a HAZARDOUS WASTE. Contact your state Department of Environmental Protection (DEP) or your regional office of the federal Environmental Protection Agency (EPA) for specific recommendations.

### Handling and Storage

Prior to working with **Sulfuric Acid** you should be trained on its proper handling and storage.

- ▶ **Sulfuric Acid** reacts violently with ALCOHOL and WATER to release HEAT and will also react violently or explosively with ORGANIC MATERIALS; COMBUSTIBLES; STRONG BASES (such as SODIUM HYDROXIDE and POTASSIUM HYDROXIDE); REDUCING AGENTS (such as LITHIUM, SODIUM, ALUMINUM and their HYDRIDES); and OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE).
- ▶ **Sulfuric Acid** reacts with MOST METALS to produce flammable and explosive *Hydrogen gas*.
- ▶ **Sulfuric Acid** is not compatible with STRONG ACIDS (such as HYDROCHLORIC and NITRIC); MOISTURE; AMINES; and many OTHER SUBSTANCES.
- ▶ Store in tightly closed containers in a cool, well-ventilated area away from HEAT SOURCES, MOIST AIR, and COMBUSTIBLES.
- ▶ **Sulfuric Acid** will absorb WATER from the air.

### Occupational Health Information Resources

The New Jersey Department of Health Occupational Health Service, offers multiple services in occupational health. These services include providing informational resources, educational materials, public presentations, and industrial hygiene and medical investigations and evaluations.

#### For more information, please contact:

New Jersey Department of Health  
Right to Know  
PO Box 368  
Trenton, NJ 08625-0368  
Phone: 609-984-2202  
Fax: 609-984-7407  
E-mail: [rtk@doh.nj.gov](mailto:rtk@doh.nj.gov)  
Web address:  
<http://nj.gov/health/workplacehealthandsafety/right-to-know>

***The Right to Know Hazardous Substance Fact Sheets  
are not intended to be copied and sold  
for commercial purposes.***



**Right to Know Hazardous Substance Fact Sheet**

**Emergency Responders Quick Reference**

Common Name: **SULFURIC ACID**

Synonyms: Battery Acid; Hydrogen Sulfate; Oil of Vitriol

CAS No: 7664-93-9

Molecular Formula: H<sub>2</sub>SO<sub>4</sub>

RTK Substance No: 1761

Description: Clear, colorless to brown, odorless liquid

HAZARD DATA		
Hazard Rating	Firefighting	Reactivity
<p><b>3 - Health</b></p> <p><b>0 - Fire</b></p> <p><b>2-W - Reactivity</b></p> <p>DOT#: UN 1830</p> <p>ERG Guide #: 137</p> <p>Hazard Class: 8 (Corrosive)</p>	<p><b>Sulfuric Acid</b> is not combustible, but it is a <b>STRONG OXIDIZER</b> that enhances the combustion of other substances.</p> <p>Extinguish fire using an agent suitable for type of surrounding fire. <b>Sulfuric Acid</b> itself does not burn.</p> <p>DO NOT USE WATER directly on <b>Sulfuric Acid</b>.</p> <p><b>POISONOUS GASES ARE PRODUCED IN FIRE</b>, including <i>Sulfur Oxides</i>.</p> <p><b>CONTAINERS MAY EXPLODE IN FIRE</b>. <b>Sulfuric Acid</b> may ignite combustibles (wood, paper and oil).</p>	<p><b>Sulfuric Acid</b> reacts violently with ALCOHOL and WATER to release HEAT and will also react violently or explosively with ORGANIC MATERIALS; COMBUSTIBLES; STRONG BASES (such as SODIUM HYDROXIDE and POTASSIUM HYDROXIDE); REDUCING AGENTS (such as LITHIUM, SODIUM, ALUMINUM and their HYDRIDES); and OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE).</p> <p><b>Sulfuric Acid</b> reacts with MOST METALS to produce flammable and explosive <i>Hydrogen gas</i>.</p> <p><b>Sulfuric Acid</b> is not compatible with STRONG ACIDS (such as HYDROCHLORIC and NITRIC); MOISTURE; AMINES; and many OTHER SUBSTANCES.</p>

SPILL/LEAKS
<p><b>Isolation Distance:</b></p> <p>Small Spill: 60 meters (200 feet)</p> <p>Large Spill: 300 meters (1,000 feet)</p> <p>Fire: 800 meters (1/2 mile)</p> <p>Neutralize spill with crushed limestone, soda ash or lime and place into sealed containers for disposal.</p> <p>DO NOT USE WATER OR WET METHOD.</p> <p>DO NOT wash into sewer.</p> <p><b>Sulfuric Acid</b> is harmful to aquatic organisms.</p>

PHYSICAL PROPERTIES	
<b>Odor Threshold:</b>	Odorless
<b>Flash Point:</b>	Nonflammable
<b>Vapor Density:</b>	3.4 (air = 1)
<b>Vapor Pressure:</b>	0.001 mm Hg at 68°F (20°C)
<b>Specific Gravity:</b>	1.8 (water = 1)
<b>Water Solubility:</b>	Soluble (mixes)
<b>Boiling Point:</b>	554° to 640°F (290° to 338°C)
<b>Melting Point:</b>	51°F (10°C)
<b>Molecular Weight:</b>	98.1
<b>pH:</b>	0.3

EXPOSURE LIMITS	
<b>OSHA:</b>	1 mg/m <sup>3</sup> , 8-hr TWA
<b>NIOSH:</b>	1 mg/m <sup>3</sup> , 10-hr TWA
<b>ACGIH:</b>	0.2 mg/m <sup>3</sup> , 8-hr TWA
<b>IDLH:</b>	15 mg/m <sup>3</sup>
	ERPG-1 = 2 mg/m <sup>3</sup>
	ERPG-2 = 10 mg/m <sup>3</sup>
	ERPG-3 = 120 mg/m <sup>3</sup>

PROTECTIVE EQUIPMENT	
<b>Gloves:</b>	Butyl, Silver Shield®/4H®, Viton and Barrier® (>8-hr breakthrough)
<b>Coveralls:</b>	Tychem® fabrics; Zytron® 300; ONESuit®/TEC; and Trelchem® HPS and VPS (>8-hr breakthrough)
<b>Respirator:</b>	<2 mg/m <sup>3</sup> - full facepiece APR with Acid gas cartridge and R or P100 prefilter >2 mg/m <sup>3</sup> - Supplied air or SCBA

HEALTH EFFECTS	
<b>Eyes:</b>	Severe irritation and burns
<b>Skin:</b>	Severe irritation and burns
<b>Inhalation:</b>	Nose, throat and lung irritation with coughing and severe shortness of breath (pulmonary edema)
	Headache, nausea and vomiting
<b>Chronic:</b>	Strong <i>inorganic acid mists</i> containing <b>Sulfuric Acid</b> cause cancer of the larynx in humans

FIRST AID AND DECONTAMINATION	
<b>Remove</b> the person from exposure.	
<b>Flush</b> eyes with large amounts of water for at least 30 minutes. Remove contact lenses if worn. Seek medical attention immediately.	
<b>Quickly</b> remove contaminated clothing and wash contaminated skin with large amounts of soap and water. Seek medical attention immediately.	
<b>Begin</b> artificial respiration if breathing has stopped and CPR if necessary.	
<b>Transfer</b> promptly to a medical facility.	
<b>Medical</b> observation is recommended as symptoms may be delayed.	

March 2016

## A.6.4: Methane



# Right to Know Hazardous Substance Fact Sheet

Common Name: **METHANE**

Synonyms: Biogas; Fire Damp; Marsh Gas; Methyl Hydride

Chemical Name: Methane

Date: April 2011      Revision: July 2016

CAS Number: 74-82-8

RTK Substance Number: 1202

DOT Number: UN 1971

### Description and Use

**Methane** is a colorless and odorless gas or a liquid under pressure. It is used as a light source and fuel, and is the major gas present in *Natural Gas*. It is also used in making many other chemicals, such as *Acetylene* and *Methanol*.

### Reasons for Citation

- ▶ **Methane** is on the Right to Know Hazardous Substance List because it is cited by ACGIH, DOT, DEP, NFPA and EPA.
- ▶ This chemical is on the Special Health Hazard Substance List.

SEE GLOSSARY ON PAGE 5.

### FIRST AID

#### Eye Contact

- ▶ Immediately flush with large amounts of water for at least 15 minutes, lifting upper and lower lids. Remove contact lenses, if worn, while rinsing.

#### Skin Contact

- ▶ Immerse affected part in warm water. Seek medical attention.

#### Inhalation

- ▶ Remove the person from exposure.
- ▶ Begin rescue breathing (using universal precautions) if breathing has stopped and CPR if heart action has stopped.
- ▶ Transfer promptly to a medical facility.

### EMERGENCY NUMBERS

Poison Control: 1-800-222-1222

CHEMTREC: 1-800-424-9300

NJDEP Hotline: 1-877-927-6337

National Response Center: 1-800-424-8802

### EMERGENCY RESPONDERS >>>> SEE LAST PAGE

#### Hazard Summary

Hazard Rating	NJDHSS	NFPA
<b>HEALTH</b>	-	2
<b>FLAMMABILITY</b>	-	4
<b>REACTIVITY</b>	-	0
FLAMMABLE POISONOUS GASES ARE PRODUCED IN FIRE CONTAINERS MAY EXPLODE IN FIRE ASPHYXIAN		

Hazard Rating Key: 0=minimal; 1=slight; 2=moderate; 3=serious; 4=severe

- ▶ **Methane** can affect you when inhaled.
- ▶ Skin contact with *liquefied Methane* can cause frostbite.
- ▶ Very high levels of **Methane** can decrease the amount of *Oxygen* in the air and cause suffocation with symptoms of headache, dizziness, weakness, nausea, vomiting, loss of coordination and judgment, increased breathing rate and loss of consciousness.
- ▶ **Methane** is a FLAMMABLE GAS and a DANGEROUS FIRE HAZARD.

### Workplace Exposure Limits

ACGIH: Maintain minimal 19.5% *Oxygen* content.

- ▶ **Methane** decreases the amount of available *Oxygen*. Routinely measure *Oxygen* content to make sure it is at least 19.5% by volume.

## METHANE

Page 2 of 6

**Determining Your Exposure**

- ▶ Read the product manufacturer's Material Safety Data Sheet (MSDS) and the label to determine product ingredients and important safety and health information about the product mixture.
- ▶ For each individual hazardous ingredient, read the New Jersey Department of Health and Senior Services Hazardous Substance Fact Sheet, available on the RTK Program website (<http://www.state.nj.us/health/workplacehealthandsafety/ri-ght-to-know/>) or in your facility's RTK Central File or Hazard Communication Standard file.
- ▶ You have a right to this information under the New Jersey Worker and Community Right to Know Act and the Public Employees Occupational Safety and Health (PEOSH) Act if you are a public worker in New Jersey, and under the federal Occupational Safety and Health Act (OSHA) if you are a private worker.
- ▶ The New Jersey Right to Know Act requires most employers to label chemicals in the workplace and requires public employers to provide their employees with information concerning chemical hazards and controls. The federal OSHA Hazard Communication Standard (29 CFR 1910.1200) and the PEOSH Hazard Communication Standard (N.J.A.C. 12:100-7) require employers to provide similar information and training to their employees.

This Fact Sheet is a summary of available information regarding the health hazards that may result from exposure. Duration of exposure, concentration of the substance and other factors will affect your susceptibility to any of the potential effects described below.

**Health Hazard Information****Acute Health Effects**

The following acute (short-term) health effects may occur immediately or shortly after exposure to **Methane**:

- ▶ Skin contact with *liquefied* Methane can cause frostbite.
- ▶ Very high levels of **Methane** can decrease the amount of **Oxygen** in the air and cause suffocation with symptoms of headache, dizziness, weakness, nausea, vomiting, loss of coordination and judgment, increased breathing rate and loss of consciousness.

**Chronic Health Effects**

The following chronic (long-term) health effects can occur at some time after exposure to **Methane** and can last for months or years:

**Cancer Hazard**

- ▶ According to the information presently available to the New Jersey Department of Health and Senior Services, **Methane** has not been tested for its ability to cause cancer in animals.

**Reproductive Hazard**

- ▶ According to the information presently available to the New Jersey Department of Health and Senior Services, **Methane** has not been tested for its ability to affect reproduction.

**Other Effects**

- ▶ No chronic (long-term) health effects are known at this time.

**Medical****Medical Testing**

There is no special test for this chemical. However, seek medical attention if illness occurs or overexposure is suspected.

Any evaluation should include a careful history of past and present symptoms with an exam. Medical tests that look for damage already done are not a substitute for controlling exposure.

You have a legal right to request copies of your medical testing under the OSHA Access to Employee Exposure and Medical Records Standard (29 CFR 1910.1020).

## METHANE

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### Workplace Controls and Practices

Very toxic chemicals, or those that are reproductive hazards or sensitizers, require expert advice on control measures if a less toxic chemical cannot be substituted. Control measures include: (1) enclosing chemical processes for severely irritating and corrosive chemicals, (2) using local exhaust ventilation for chemicals that may be harmful with a single exposure, and (3) using general ventilation to control exposures to skin and eye irritants. For further information on workplace controls, consult the NIOSH document on Control Banding at [www.cdc.gov/niosh/topics/ctrlbanding/](http://www.cdc.gov/niosh/topics/ctrlbanding/).

The following work practices are also recommended:

- ▶ Label process containers.
- ▶ Provide employees with hazard information and training.
- ▶ Monitor airborne chemical concentrations.
- ▶ Use engineering controls if concentrations exceed recommended exposure levels.
- ▶ Provide eye wash fountains and emergency showers.
- ▶ Wash or shower if skin comes in contact with a hazardous material.
- ▶ Always wash at the end of the workshift.
- ▶ Change into clean clothing if clothing becomes contaminated.
- ▶ Do not take contaminated clothing home.
- ▶ Get special training to wash contaminated clothing.
- ▶ Do not eat, smoke, or drink in areas where chemicals are being handled, processed or stored.
- ▶ Wash hands carefully before eating, smoking, drinking, applying cosmetics or using the toilet.

In addition, the following may be useful or required:

- ▶ Specific actions are required for this chemical by OSHA. Refer to the OSHA *Compressed Gases* Standard (29 CFR 1910.101).
- ▶ Before entering a confined space where **Methane** is present, check to make sure sufficient *Oxygen* (19.5%) exists.
- ▶ Before entering a confined space where **Methane** may be present, check to make sure that an explosive concentration does not exist.

### Personal Protective Equipment

The OSHA Personal Protective Equipment Standard (29 CFR 1910.132) requires employers to determine the appropriate personal protective equipment for each hazard and to train employees on how and when to use protective equipment.

The following recommendations are only guidelines and may not apply to every situation.

#### Gloves and Clothing

- ▶ Avoid skin contact with **Methane**. Wear personal protective equipment made from material that can not be permeated or degraded by this substance. Safety equipment suppliers and manufacturers can provide recommendations on the most protective glove and clothing material for your operation.

- ▶ Where exposure to cold equipment, vapors, or liquid may occur, employees should be provided with *insulated* gloves and special clothing designed to prevent the freezing of body tissues.
- ▶ The recommended protective clothing material for **Methane** is Tychem® CSM, or the equivalent.
- ▶ All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

#### Eye Protection

- ▶ Wear non-vented goggles when working with liquids that splash or when vapors and/or fumes are present. A face shield is also required if the liquid is severely irritating or corrosive to the skin and eyes.

#### Respiratory Protection

**Improper use of respirators is dangerous.** Respirators should only be used if the employer has implemented a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing, and medical exams, as described in the OSHA Respiratory Protection Standard (29 CFR 1910.134).

- ▶ Where the potential exists for exposure over **1,000 ppm**, use a NIOSH approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode. For increased protection use in combination with an auxiliary self-contained breathing apparatus or an emergency escape air cylinder.
- ▶ Exposure to **5,000 ppm** is immediately dangerous to life and health. If the possibility of exposure above **5,000 ppm** exists, use a NIOSH approved self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode equipped with an emergency escape air cylinder.
- ▶ Exposure to **Methane** is dangerous because it can replace *Oxygen* and lead to suffocation. Only NIOSH approved self-contained breathing apparatus with a full facepiece operated in the positive pressure mode should be used in *Oxygen* deficient environments.

### Fire Hazards

If employees are expected to fight fires, they must be trained and equipped as stated in the OSHA Fire Brigades Standard (29 CFR 1910.156).

- ▶ **Methane** is a FLAMMABLE GAS.
- ▶ Stop flow of gas or allow to burn.
- ▶ **Methane** is an explosion hazard in enclosed areas.
- ▶ *Liquefied Methane* floats on water and boils. The vapor cloud produced is FLAMMABLE.
- ▶ POISONOUS GASES ARE PRODUCED IN FIRE.
- ▶ CONTAINERS MAY EXPLODE IN FIRE.
- ▶ Use water spray to keep fire-exposed containers cool.
- ▶ Vapors may travel to a source of ignition and flash back.

**METHANE**

Page 4 of 6

**Spills and Emergencies**

If employees are required to clean-up spills, they must be properly trained and equipped. The OSHA Hazardous Waste Operations and Emergency Response Standard (29 CFR 1910.120) may apply.

If **Methane** is leaked, take the following steps:

- ▶ Evacuate personnel and secure and control entrance to the area.
- ▶ Eliminate ignition sources.
- ▶ Ventilate area of leak to disperse the gas.
- ▶ Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty.
- ▶ Conduct air monitoring to determine that *Oxygen* levels are above 19.5% and the Lower Explosive Limit (LEL) is not being exceeded.
- ▶ Turn leaking cylinder with leak up to prevent escape of gas in liquid state.
- ▶ Keep **Methane** out of confined spaces, such as sewers, because of the possibility of an explosion.
- ▶ It may be necessary to contain and dispose of **Methane** as a HAZARDOUS WASTE. Contact your state Department of Environmental Protection (DEP) or your regional office of the federal Environmental Protection Agency (EPA) for specific recommendations.

**Handling and Storage**

Prior to working with **Methane** you should be trained on its proper handling and storage.

- ▶ **Methane** reacts violently with OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE).
- ▶ **Methane** can react violently with *boiling* WATER and *cold* WATER.
- ▶ *Liquefied Methane* combined with *liquefied* OXYGEN can form an explosive mixture.
- ▶ Store in tightly closed containers in a cool, well-ventilated area.
- ▶ Sources of ignition, such as smoking and open flames, are prohibited where **Methane** is used, handled, or stored.
- ▶ Metal containers involving the transfer of **Methane** should be grounded and bonded.
- ▶ Use only non-sparking tools and equipment, especially when opening and closing containers of **Methane**.

**Occupational Health Information Resources**

The New Jersey Department of Health and Senior Services, Occupational Health Service, offers multiple services in occupational health. These services include providing informational resources, educational materials, public presentations, and industrial hygiene and medical investigations and evaluations.

**For more information, please contact:**

New Jersey Department of Health & Senior Services  
Right to Know Program  
PO Box 368  
Trenton, NJ 08625-0368  
Phone: 609-984-2202  
Fax: 609-984-7407  
E-mail: [rtk@doh.nj.gov](mailto:rtk@doh.nj.gov)  
Web address:  
<http://www.state.nj.us/health/workplacehealthandsafety/right-to-know/>

*The Right to Know Hazardous Substance Fact Sheets are not intended to be copied and sold for commercial purposes.*




**Right to Know Hazardous Substance Fact Sheet**
**Emergency  
 Responders  
 Quick Reference**

 Common Name: **METHANE**

Synonyms: Biogas; Fire Damp; Marsh Gas; Methyl Hydride

CAS No: 74-82-8

 Molecular Formula: CH<sub>4</sub>

RTK Substance No: 1202

Description: Colorless and odorless gas or a liquid under pressure

HAZARD DATA		
Hazard Rating	Firefighting	Reactivity
<b>2 - Health</b> <b>4 - Fire</b> <b>0 - Reactivity</b> DOT#: UN 1971 ERG Guide #: 115 Hazard Class: 2.1 (Flammable gas)	<b>FLAMMABLE GAS</b> Stop flow of gas or allow to burn. <b>Methane</b> is an explosion hazard in enclosed areas. <i>Liquefied Methane</i> floats on water and boils. The vapor cloud produced is <b>FLAMMABLE</b> . <b>POISONOUS GASES ARE PRODUCED IN FIRE. CONTAINERS MAY EXPLODE IN FIRE.</b> Use water spray to keep fire-exposed containers cool. Vapors may travel to a source of ignition and flash back.	<b>Methane</b> reacts violently with <b>OXIDIZING AGENTS</b> (such as <b>PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE</b> ). <b>Methane</b> can react violently with <i>boiling WATER</i> and <i>cold WATER</i> . <i>Liquefied Methane</i> combined with <i>liquefied OXYGEN</i> can form an explosive mixture.

SPILL/LEAKS
<b>Isolation Distance:</b> Spill: 100 meters (330 feet) Fire: 800 meters (1/2 mile) Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty. Ground and bond all metal containers when transferring <b>Methane</b> and use non-sparking tools and equipment. Turn leaking cylinder with leak up to prevent escape of gas in liquid state. Keep <b>Methane</b> out of confined spaces, such as sewers, because of the possibility of an explosion. <b>Methane</b> is NOT harmful to aquatic life.

PHYSICAL PROPERTIES	
<b>Odor Threshold:</b>	Odorless
<b>Flash Point:</b>	-306 °F (-188 °C)
<b>LEL:</b>	5%
<b>UEL:</b>	15%
<b>Auto Ignition Temp:</b>	999 °F (537 °C)
<b>Vapor Density:</b>	0.55 (air = 1)
<b>Vapor Pressure:</b>	>760 mm Hg at 68 °F (20 °C)
<b>Specific Gravity:</b>	0.42 (water = 1)
<b>Water Solubility:</b>	Very slightly soluble
<b>Boiling Point:</b>	-259 °F (-162 °C)
<b>Freezing Point:</b>	-296.5 °F (-183 °C)
<b>Critical Temp:</b>	-116.5 °F (-82.5 °C)
<b>Ionization Potential:</b>	12.51 eV
<b>Molecular Weight:</b>	16.04

EXPOSURE LIMITS
<b>ACGIH:</b> Maintain 19.5% <i>Oxygen</i> content The Protective Action Criteria values are: PAC-1 = 65,000 ppm    PAC-2 = 230,000 ppm PAC-3 = 400,000 ppm

PROTECTIVE EQUIPMENT	
<b>Gloves:</b>	<i>Insulated materials</i>
<b>Coveralls:</b>	Tychem® CSM (>8-hr breakthrough) <b>Use turn out gear or flash protection if ignition/fire is the greatest hazard!</b>
<b>Respirator:</b>	< 19.5% <i>Oxygen</i> - SCBA

HEALTH EFFECTS	
<b>Eyes:</b>	No information available
<b>Skin:</b>	Contact with <i>liquefied gas</i> can cause frostbite
<b>Inhalation:</b>	Headache, dizziness, weakness, nausea, vomiting, loss of coordination, increased breathing rate and loss of consciousness (ASPHYXIAN)

FIRST AID AND DECONTAMINATION	
<b>Remove</b> the person from exposure.	
<b>Flush</b> eyes with large amounts of water for at least 15 minutes.	
<b>Immerse</b> affected part in warm water. Seek medical attention.	
<b>Begin</b> artificial respiration if breathing has stopped and CPR if necessary.	
<b>Transfer</b> promptly to a medical facility.	

July 2016

## A.6.5: Propane



# Right to Know Hazardous Substance Fact Sheet

Common Name: **PROPANE**

Synonyms: Dimethylmethane; Propyl Hydride

Chemical Name: Propane

Date: May 2010 Revision: June 2015

CAS Number: 74-98-6

RTK Substance Number: 1594

DOT Number: UN 1978

### Description and Use

**Propane** is a colorless, odorless gas when pure or it may have a faint petroleum-like odor. It is usually shipped as a liquefied gas with a foul-smelling odorant added, and is used as a fuel, refrigerant, solvent and aerosol propellant.

- ▶ **ODOR THRESHOLD = 20,000 ppm**
- ▶ Odor thresholds vary greatly. Do not rely on odor alone to determine potentially hazardous exposures.

### Reasons for Citation

- ▶ **Propane** is on the Right to Know Hazardous Substance List because it is cited by OSHA, ACGIH, DOT, NIOSH, DEP, NFPA, and EPA.
- ▶ This chemical is on the Special Health Hazard Substance List.

SEE GLOSSARY ON PAGE 5.

### FIRST AID

#### Eye Contact

- ▶ Immediately flush with large amounts of water for at least 15 minutes, lifting upper and lower lids. Remove contact lenses, if worn, while flushing. Seek medical attention.

#### Skin Contact

- ▶ Immerse affected part in warm water. Seek medical attention.

#### Inhalation

- ▶ Remove the person from exposure.
- ▶ Begin rescue breathing (using universal precautions) if breathing has stopped and CPR if heart action has stopped.
- ▶ Transfer promptly to a medical facility.

### EMERGENCY NUMBERS

Poison Control: 1-800-222-1222

CHEMTREC: 1-800-424-9300

NJDEP Hotline: 1-877-927-6337

National Response Center: 1-800-424-8802

### EMERGENCY RESPONDERS >>>> SEE LAST PAGE

#### Hazard Summary

Hazard Rating	NJDHSS	NFPA
HEALTH	-	2
FLAMMABILITY	-	4
REACTIVITY	-	0

FLAMMABLE  
POISONOUS GASES ARE PRODUCED IN FIRE  
CONTAINERS MAY EXPLODE IN FIRE

Hazard Rating Key: 0=minimal; 1=slight; 2=moderate; 3=serious; 4=severe

- ▶ **Propane** can affect you when inhaled.
- ▶ Contact with *liquefied Propane* may cause frostbite.
- ▶ Exposure to high concentrations of **Propane** can decrease the amount of *Oxygen* in the air and cause suffocation with symptoms of headache, dizziness, lightheadedness and passing out.
- ▶ **Propane** is a FLAMMABLE GAS and a DANGEROUS FIRE HAZARD.

### Workplace Exposure Limits

OSHA: The legal airborne permissible exposure limit (PEL) is **1,000 ppm** averaged over an 8-hour workshift.

NIOSH: The recommended airborne exposure limit (REL) is **1,000 ppm** averaged over a 10-hour workshift.

ACGIH: The threshold limit value (TLV) is **1,000 ppm** averaged over an 8-hour workshift.

- ▶ **Propane** decreases the amount of available *Oxygen*. Routinely measure *Oxygen* content to make sure it is at least 19.5% by volume.

## PROPANE

Page 2 of 6

**Determining Your Exposure**

- ▶ Read the product manufacturer's Material Safety Data Sheet (MSDS) and the label to determine product ingredients and important safety and health information about the product mixture.
- ▶ For each individual hazardous ingredient, read the New Jersey Department of Health Hazardous Substance Fact Sheet, available on the RTK website (<http://nj.gov/health/workplacehealthandsafety/right-to-know>) or in your facility's RTK Central File or Hazard Communication Standard file.
- ▶ You have a right to this information under the New Jersey Worker and Community Right to Know Act and the Public Employees Occupational Safety and Health (PEOSH) Act if you are a public worker in New Jersey, and under the federal Occupational Safety and Health Act (OSHA) if you are a private worker.
- ▶ The New Jersey Right to Know Act requires most employers to label chemicals in the workplace and requires public employers to provide their employees with information concerning chemical hazards and controls. The federal OSHA Hazard Communication Standard (29 CFR 1910.1200) and the PEOSH Hazard Communication Standard (N.J.A.C. 12:100-7) require employers to provide similar information and training to their employees.

This Fact Sheet is a summary of available information regarding the health hazards that may result from exposure. Duration of exposure, concentration of the substance and other factors will affect your susceptibility to any of the potential effects described below.

**Health Hazard Information****Acute Health Effects**

The following acute (short-term) health effects may occur immediately or shortly after exposure to **Propane**:

- ▶ Contact with *liquefied Propane* may cause frostbite.
- ▶ Exposure to high concentrations of **Propane** can decrease the amount of *Oxygen* in the air and cause suffocation with symptoms of headache, dizziness, lightheadedness, weakness, nausea, vomiting, loss of coordination and judgment, passing out and even death.

**Chronic Health Effects**

The following chronic (long-term) health effects can occur at some time after exposure to **Propane** and can last for months or years:

**Cancer Hazard**

- ▶ According to the information presently available to the New Jersey Department of Health, **Propane** has not been tested for its ability to cause cancer in animals.

**Reproductive Hazard**

- ▶ According to the information presently available to the New Jersey Department of Health, **Propane** has not been tested for its ability to affect reproduction.

**Other Effects**

- ▶ No chronic (long-term) health effects are known at this time.

**Medical****Medical Testing**

There is no special test for this chemical. However, seek medical attention if illness occurs or overexposure is suspected.

Any evaluation should include a careful history of past and present symptoms with an exam. Medical tests that look for damage already done are not a substitute for controlling exposure.

Request copies of your medical testing. You have a legal right to this information under the OSHA Access to Employee Exposure and Medical Records Standard (29 CFR 1910.1020).

## PROPANE

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### Workplace Controls and Practices

Very toxic chemicals, or those that are reproductive hazards or sensitizers, require expert advice on control measures if a less toxic chemical cannot be substituted. Control measures include: (1) enclosing chemical processes for severely irritating and corrosive chemicals, (2) using local exhaust ventilation for chemicals that may be harmful with a single exposure, and (3) using general ventilation to control exposures to skin and eye irritants. For further information on workplace controls, consult the NIOSH document on Control Banding at [www.cdc.gov/niosh/topics/ctrlbanding/](http://www.cdc.gov/niosh/topics/ctrlbanding/).

The following work practices are also recommended:

- ▶ Label process containers.
- ▶ Provide employees with hazard information and training.
- ▶ Monitor airborne chemical concentrations.
- ▶ Use engineering controls if concentrations exceed recommended exposure levels.
- ▶ Provide eye wash fountains and emergency showers.
- ▶ Wash or shower if skin comes in contact with a hazardous material.
- ▶ Always wash at the end of the workshift.
- ▶ Change into clean clothing if clothing becomes contaminated.
- ▶ Do not take contaminated clothing home.
- ▶ Get special training to wash contaminated clothing.
- ▶ Do not eat, smoke, or drink in areas where chemicals are being handled, processed or stored.
- ▶ Wash hands carefully before eating, smoking, drinking, applying cosmetics or using the toilet.

In addition, the following may be useful or required:

- ▶ Before entering a confined space where **Propane** is present, check to make sure sufficient *Oxygen* (19.5%) exists.
- ▶ Before entering a confined space where **Propane** may be present, check to make sure that an explosive concentration does not exist.

### Personal Protective Equipment

The OSHA Personal Protective Equipment Standard (29 CFR 1910.132) requires employers to determine the appropriate personal protective equipment for each hazard and to train employees on how and when to use protective equipment.

The following recommendations are only guidelines and may not apply to every situation.

#### Gloves and Clothing

- ▶ Avoid skin contact with **Propane**. Wear personal protective equipment made from material which can not be permeated or degraded by this substance. Safety equipment suppliers and manufacturers can provide recommendations on the most protective glove and clothing material for your operation.
- ▶ Safety equipment manufacturers recommend Nitrile and Neoprene for gloves, and Tychem® Responder®, or the equivalent, as a protective material for clothing. Use turn out gear or flash protection if ignition/fire is the greatest hazard.

- ▶ Where exposure to cold equipment, vapors, or liquid may occur, employees should be provided with *insulated* gloves and special clothing designed to prevent the freezing of body tissues.
- ▶ All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

#### Eye Protection

- ▶ Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- ▶ If additional protection is needed for the entire face, use in combination with a face shield. A face shield should not be used without another type of eye protection.

#### Respiratory Protection

**Improper use of respirators is dangerous.** Respirators should only be used if the employer has implemented a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing, and medical exams, as described in the OSHA Respiratory Protection Standard (29 CFR 1910.134).

- ▶ Where the potential exists for exposure over **1,000 ppm**, use a NIOSH approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode. For increased protection use in combination with an auxiliary self-contained breathing apparatus or an emergency escape air cylinder.
- ▶ Exposure to **2,100 ppm** is immediately dangerous to life and health. If the possibility of exposure above **2,100 ppm** exists, use a NIOSH approved self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode equipped with an emergency escape air cylinder.
- ▶ Exposure to **Propane** is dangerous because it can replace *Oxygen* and lead to suffocation. Only a NIOSH approved self-contained breathing apparatus with a full facepiece operated in the positive pressure mode should be used in *Oxygen* deficient environments.

### Fire Hazards

If employees are expected to fight fires, they must be trained and equipped as stated in the OSHA Fire Brigades Standard (29 CFR 1910.156).

- ▶ **Propane** is a FLAMMABLE GAS.
- ▶ Stop flow of gas and use water spray to disperse vapors.
- ▶ POISONOUS GASES ARE PRODUCED IN FIRE.
- ▶ CONTAINERS MAY EXPLODE IN FIRE.
- ▶ Use water spray to keep fire-exposed containers cool.
- ▶ Vapor is heavier than air and may travel a distance to cause a fire or explosion far from the source or flash back.
- ▶ Flow, agitation, low humidity and other factors may generate electrostatic charges resulting in fire and/or explosion.
- ▶ **Propane** may form an ignitable vapor/air mixture in closed tanks or containers.

**PROPANE**

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**Spills and Emergencies**

If employees are required to clean-up spills, they must be properly trained and equipped. The OSHA Hazardous Waste Operations and Emergency Response Standard (29 CFR 1910.120) may apply.

If **Propane** is leaked, take the following steps:

- ▶ Evacuate personnel and secure and control entrance to the area.
- ▶ Eliminate ignition sources.
- ▶ Ventilate area of leak to disperse the gas.
- ▶ Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty.
- ▶ Conduct air monitoring to determine that *Oxygen* levels are above 19.5% and the Lower Explosive Limit (LEL) is not being exceeded.
- ▶ **Propane** may "pool" or "settle" in low areas and may remain in a fixed location for a long period of time.
- ▶ Keep **Propane** out of confined spaces, such as sewers, because of the possibility of an explosion.
- ▶ Turn leaking cylinder with leak up to prevent escape of gas in liquid state.
- ▶ It may be necessary to contain and dispose of **Propane** as a HAZARDOUS WASTE. Contact your state Department of Environmental Protection (DEP) or your regional office of the federal Environmental Protection Agency (EPA) for specific recommendations.

**Handling and Storage**

Prior to working with **Propane** you should be trained on its proper handling and storage.

- ▶ **Propane** may react violently with CHLORINE DIOXIDE and other OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE).
- ▶ Store in tightly closed containers in a cool, well-ventilated area away from COMBUSTIBLES.
- ▶ Sources of ignition, such as smoking and open flames, are prohibited where **Propane** is used, handled, or stored.
- ▶ Metal containers involving the transfer of **Propane** should be grounded and bonded.
- ▶ Use explosion-proof electrical equipment and fittings wherever **Propane** is used, handled, manufactured, or stored.
- ▶ Use only non-sparking tools and equipment, especially when opening and closing containers of **Propane**.
- ▶ **Propane** may accumulate static electricity when being filled into properly grounded containers.

**Occupational Health Information Resources**

The New Jersey Department of Health and Occupational Health Service, offers multiple services in occupational health. These services include providing informational resources, educational materials, public presentations, and industrial hygiene and medical investigations and evaluations.

**For more information, please contact:**

New Jersey Department of Health  
Right to Know  
PO Box 368  
Trenton, NJ 08625-0368  
Phone: 609-984-2202  
Fax: 609-984-7407  
E-mail: [rtk@doh.nj.gov](mailto:rtk@doh.nj.gov)  
Web address:  
<http://nj.gov/health/workplacehealthandsafety/right-to-know>

***The Right to Know Hazardous Substance Fact Sheets are not intended to be copied and sold for commercial purposes.***



**Right to Know Hazardous Substance Fact Sheet**



Common Name: **PROPANE**

Synonyms: Dimethylmethane; Propyl Hydride

CAS No: 74-98-6

Molecular Formula: C<sub>3</sub>H<sub>8</sub>

RTK Substance No: 1594

Description: Colorless, odorless gas when pure, or may have a faint petroleum-like odor, and is usually shipped as a liquefied gas with a foul-smelling odorant added

HAZARD DATA	
<b>Hazard Rating</b>	<b>Firefighting</b>
<p><b>2 - Health</b></p> <p><b>4 - Fire</b></p> <p><b>0 - Reactivity</b></p> <p><b>DOT#:</b> UN 1978</p> <p><b>ERG Guide #:</b> 115</p> <p><b>Hazard Class:</b> 2.1 (Flammable gas)</p>	<p><b>FLAMMABLE GAS</b></p> <p>Stop flow of gas and use water spray to disperse vapors.</p> <p><b>POISONOUS GASES ARE PRODUCED IN FIRE.</b></p> <p><b>CONTAINERS MAY EXPLODE IN FIRE.</b></p> <p>Use water spray to keep fire-exposed containers cool.</p> <p>Vapor is heavier than air and may travel a distance to cause a fire or explosion far from the source or flash back.</p> <p>Flow, agitation, low humidity and other factors may generate electrostatic charges resulting in fire and/or explosion.</p> <p><b>Propane</b> may form an ignitable vapor/air mixture in closed tanks or containers.</p>
<b>Reactivity</b>	
<p><b>Propane</b> may react violently with <b>CHLORINE DIOXIDE</b> and other <b>OXIDIZING AGENTS</b> (such as <b>PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE</b> and <b>FLUORINE</b>).</p>	
<b>SPILL/LEAKS</b>	<b>PHYSICAL PROPERTIES</b>
<p><b>Isolation Distance:</b></p> <p>Spill: 100 meters (330 feet)    Fire: 1,600 meters (1 mile)</p> <p>Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty.</p> <p>Conduct air monitoring to determine that <i>Oxygen</i> levels are above 19.5% and the Lower Explosive Limit (LEL) is not being exceeded.</p> <p>Use only non-sparking tools and equipment, especially when opening and closing containers of <b>Propane</b>.</p> <p><b>Propane</b> may "pool" or "settle" in low areas and may remain in a fixed location for a long period of time.</p> <p>Keep <b>Propane</b> out of confined spaces, such as sewers, because of the possibility of an explosion.</p> <p>Turn leaking cylinder with leak up to prevent escape of gas in liquid state.</p> <p><b>Propane</b> is not harmful to aquatic life.</p>	<p><b>Odor Threshold:</b> 20,000 ppm</p> <p><b>Flash Point:</b> -155°F (-104°C)</p> <p><b>LEL:</b> 2.1%</p> <p><b>UEL:</b> 9.5%</p> <p><b>Auto Ignition Temp:</b> 842°F (450°C)</p> <p><b>Vapor Density:</b> 1.6 (air = 1)</p> <p><b>Vapor Pressure:</b> &gt;760 mm Hg at 68°F (20°C)</p> <p><b>Specific Gravity:</b> 0.58 (water = 1)</p> <p><b>Water Solubility:</b> Slightly soluble</p> <p><b>Boiling Point:</b> -44°F (-42°C)</p> <p><b>Freezing Point:</b> -305.9°F (-187.7°C)</p> <p><b>Critical Temperature:</b> 207°F (97°C)</p> <p><b>Ionization Potential:</b> 11.07 eV</p> <p><b>Molecular Weight:</b> 44.09</p>
<b>EXPOSURE LIMITS</b>	<b>PROTECTIVE EQUIPMENT</b>
<p><b>OSHA:</b> 1,000 ppm, 8-hr TWA</p> <p><b>NIOSH:</b> 1,000 ppm, 10-hr TWA</p> <p><b>ACGIH:</b> 1,000 ppm, 8-hr TWA</p> <p><b>IDLH:</b> 2,100 ppm</p> <p>The Protective Action Criteria values are:</p> <p>PAC-1 = 5,500 ppm    PAC-2 = 17,000 ppm</p> <p>PAC-3 = 33.00 ppm</p>	<p><b>Gloves:</b> <i>Insulated</i> Nitrile or Neoprene (&gt;8-hr breakthrough)</p> <p><b>Coveralls:</b> <b>Use turn out gear or flash protection if ignition/fire is the greatest hazard!</b> Tychem® Responder® (&gt;8-hr breakthrough)</p> <p><b>Respirator:</b> &gt;1,000 ppm or &lt;19.5% <i>Oxygen</i> - SCBA</p>
<b>HEALTH EFFECTS</b>	<b>FIRST AID AND DECONTAMINATION</b>
<p><b>Eyes:</b> Contact with liquefied gas may cause frostbite</p> <p><b>Skin:</b> Contact with liquefied gas may cause frostbite</p> <p><b>Inhalation:</b> Headache, dizziness, lightheadedness, passing out, and death</p>	<p><b>Remove</b> the person from exposure.</p> <p><b>Flush</b> eyes with large amounts of water for at least 15 minutes. Remove contact lenses if worn. Seek medical attention.</p> <p><b>Immerse</b> affected part in warm water. Seek medical attention.</p> <p><b>Begin</b> artificial respiration if breathing has stopped and CPR if necessary.</p> <p><b>Transfer</b> promptly to a medical facility.</p>

June 2015

## A.6.6: Sulfur Dioxide



# Right to Know Hazardous Substance Fact Sheet

Common Name: **SULFUR DIOXIDE**

Synonyms: Sulfurous Oxide; Sulfur Oxide

Chemical Name: Sulfur Dioxide

Date: June 2000      Revision: May 2010

CAS Number: 7446-09-5

RTK Substance Number: 1759

DOT Number: UN 1079

### Description and Use

**Sulfur Dioxide** is a colorless gas with a strong, irritating odor, that is often shipped as a liquid under pressure. It is used as a bleaching agent, refrigerant, and solvent, and occurs as an off-gas from smelters and electrical power plants.

- ▶ **ODOR THRESHOLD = 0.3 to 5 ppm**
- ▶ Odor thresholds vary greatly. Do not rely on odor alone to determine potentially hazardous exposures.

### Reasons for Citation

- ▶ **Sulfur Dioxide** is on the Right to Know Hazardous Substance List because it is cited by OSHA, ACGIH, DOT, NIOSH, DEP, IARC, NFPA and EPA.

SEE GLOSSARY ON PAGE 5.

### FIRST AID

#### Eye Contact

- ▶ Immediately flush with large amounts of water for at least 15 minutes, lifting upper and lower lids. Remove contact lenses, if worn, while flushing. Seek medical attention.

#### Skin Contact

- ▶ Immerse affected part in warm water. Seek medical attention.

#### Inhalation

- ▶ Remove the person from exposure.
- ▶ Begin rescue breathing (using universal precautions) if breathing has stopped and CPR if heart action has stopped.
- ▶ Transfer promptly to a medical facility.
- ▶ Medical observation is recommended for 24 to 48 hours after overexposure, as pulmonary edema may be delayed.

### EMERGENCY NUMBERS

Poison Control: 1-800-222-1222

CHEMTREC: 1-800-424-9300

NJDEP Hotline: 1-877-927-6337

National Response Center: 1-800-424-8802

EMERGENCY RESPONDERS >>>> SEE LAST PAGE

### Hazard Summary

Hazard Rating	NJDOH	NFPA
HEALTH	-	3
FLAMMABILITY	-	0
REACTIVITY	-	0

POISONOUS GASES ARE PRODUCED IN FIRE  
CONTAINERS MAY EXPLODE IN FIRE  
DOES NOT BURN

Hazard Rating Key: 0=minimal; 1=slight; 2=moderate; 3=serious; 4=severe

- ▶ **Sulfur Dioxide** can affect you when inhaled and by passing through the skin.
- ▶ Contact can irritate and burn the skin and eyes with possible eye damage.
- ▶ Direct contact with the *liquid* may cause frostbite.
- ▶ Inhaling **Sulfur Dioxide** can irritate the nose and throat.
- ▶ Inhaling **Sulfur Dioxide** can irritate the lungs. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency.
- ▶ Repeated exposure can cause loss of sense of smell, headache, nausea and dizziness.

### Workplace Exposure Limits

OSHA: The legal airborne permissible exposure limit (PEL) is **5 ppm** averaged over an 8-hour workshift.

NIOSH: The recommended airborne exposure limit (REL) is **2 ppm** averaged over a 10-hour workshift and **5 ppm**, not to be exceeded during any 15-minute work period.

ACGIH: The threshold limit value (TLV) is **0.25 ppm** averaged over an 8-hour workshift.

- ▶ The above exposure limits are for air levels only. When skin contact also occurs, you may be overexposed, even though air levels are less than the limits listed above.

## SULFUR DIOXIDE

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## Determining Your Exposure

- ▶ Read the product manufacturer's Material Safety Data Sheet (MSDS) and the label to determine product ingredients and important safety and health information about the product mixture.
- ▶ For each individual hazardous ingredient, read the New Jersey Department of Health Hazardous Substance Fact Sheet, available on the RTK website ([www.nj.gov/health/eoh/rtkweb](http://www.nj.gov/health/eoh/rtkweb)) or in your facility's RTK Central File or Hazard Communication Standard file.
- ▶ You have a right to this information under the New Jersey Worker and Community Right to Know Act and the Public Employees Occupational Safety and Health (PEOSH) Act if you are a public worker in New Jersey, and under the federal Occupational Safety and Health Act (OSHA) if you are a private worker.
- ▶ The New Jersey Right to Know Act requires most employers to label chemicals in the workplace and requires public employers to provide their employees with information concerning chemical hazards and controls. The federal OSHA Hazard Communication Standard (29 CFR 1910.1200) and the PEOSH Hazard Communication Standard (N.J.A.C. 12:100-7) require employers to provide similar information and training to their employees.

This Fact Sheet is a summary of available information regarding the health hazards that may result from exposure. Duration of exposure, concentration of the substance and other factors will affect your susceptibility to any of the potential effects described below.

## Health Hazard Information

**Acute Health Effects**

The following acute (short-term) health effects may occur immediately or shortly after exposure to **Sulfur Dioxide**:

- ▶ Contact can irritate and burn the skin and eyes with possible eye damage.
- ▶ Direct contact with the *liquid* may cause frostbite.
- ▶ Inhaling **Sulfur Dioxide** can irritate the nose and throat.
- ▶ Inhaling **Sulfur Dioxide** can irritate the lungs causing coughing and/or shortness of breath. Higher exposures may cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath.

**Chronic Health Effects**

The following chronic (long-term) health effects can occur at some time after exposure to **Sulfur Dioxide** and can last for months or years:

**Cancer Hazard**

- ▶ While **Sulfur Dioxide** has been tested, it is not classifiable as to its potential to cause cancer.

**Reproductive Hazard**

- ▶ **Sulfur Dioxide** may decrease fertility in males and females.

**Other Effects**

- ▶ Repeated exposure can cause loss of sense of smell, headache, nausea, vomiting and dizziness.
- ▶ **Sulfur Dioxide** can irritate the lungs. Repeated exposure may cause bronchitis to develop with coughing, phlegm, and/or shortness of breath.

## Medical

**Medical Testing**

For frequent or potentially high exposure (half the TLV or greater), the following are recommended before beginning work and at regular times after that:

- ▶ Lung function tests

Any evaluation should include a careful history of past and present symptoms with an exam. Medical tests that look for damage already done are not a substitute for controlling exposure.

Request copies of your medical testing. You have a legal right to this information under the OSHA Access to Employee Exposure and Medical Records Standard (29 CFR 1910.1020).

**Mixed Exposures**

- ▶ Smoking can cause heart disease, lung cancer, emphysema, and other respiratory problems. It may worsen respiratory conditions caused by chemical exposure. Even if you have smoked for a long time, stopping now will reduce your risk of developing health problems.

**Conditions Made Worse By Exposure**

- ▶ People with chronic lung disease (bronchitis, emphysema) may have their condition become worse after exposure to **Sulfur Dioxide**.



## SULFUR DIOXIDE

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### Workplace Controls and Practices

Very toxic chemicals, or those that are reproductive hazards or sensitizers, require expert advice on control measures if a less toxic chemical cannot be substituted. Control measures include: (1) enclosing chemical processes for severely irritating and corrosive chemicals, (2) using local exhaust ventilation for chemicals that may be harmful with a single exposure, and (3) using general ventilation to control exposures to skin and eye irritants. For further information on workplace controls, consult the NIOSH document on Control Banding at [www.cdc.gov/niosh/topics/ctrlbanding/](http://www.cdc.gov/niosh/topics/ctrlbanding/).

The following work practices are also recommended:

- ▶ Label process containers.
- ▶ Provide employees with hazard information and training.
- ▶ Monitor airborne chemical concentrations.
- ▶ Use engineering controls if concentrations exceed recommended exposure levels.
- ▶ Provide eye wash fountains and emergency showers.
- ▶ Wash or shower if skin comes in contact with a hazardous material.
- ▶ Always wash at the end of the workshift.
- ▶ Change into clean clothing if clothing becomes contaminated.
- ▶ Do not take contaminated clothing home.
- ▶ Get special training to wash contaminated clothing.
- ▶ Do not eat, smoke, or drink in areas where chemicals are being handled, processed or stored.
- ▶ Wash hands carefully before eating, smoking, drinking, applying cosmetics or using the toilet.

In addition, the following may be useful or required:

- ▶ Specific actions are required for this chemical by OSHA. Refer to the OSHA *Compressed Gases* Standard (29 CFR 1910.101).
- ▶ Where possible, transfer **Sulfur Dioxide** from cylinders or other containers to process containers in an enclosed system.

### Personal Protective Equipment

The OSHA Personal Protective Equipment Standard (29 CFR 1910.132) requires employers to determine the appropriate personal protective equipment for each hazard and to train employees on how and when to use protective equipment.

The following recommendations are only guidelines and may not apply to every situation.

#### Gloves and Clothing

- ▶ Avoid skin contact with **Sulfur Dioxide**. Wear personal protective equipment made from material which can not be permeated or degraded by this substance. Safety equipment suppliers and manufacturers can provide recommendations on the most protective glove and clothing material for your operation.
- ▶ Safety equipment manufacturers recommend Butyl and Neoprene for gloves, and Tychem® SL, BR, Responder®, and TK, or the equivalent, as protective materials for clothing.

- ▶ Where exposure to cold equipment, vapors, or liquid may occur, employees should be provided with *insulated* gloves and special clothing designed to prevent the freezing of body tissues.
- ▶ All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

#### Eye Protection

- ▶ Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- ▶ Wear indirect-vent, impact and splash resistant goggles when working with liquids.
- ▶ Wear a face shield along with goggles when working with corrosive, highly irritating or toxic substances.

#### Respiratory Protection

**Improper use of respirators is dangerous.** Respirators should only be used if the employer has implemented a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing, and medical exams, as described in the OSHA Respiratory Protection Standard (29 CFR 1910.134).

- ▶ Where the potential exists for exposure over **0.25 ppm**, use a NIOSH approved full facepiece respirator with an acid gas cartridge which is specifically approved for **Sulfur Dioxide**. Increased protection is obtained from full facepiece powered-air purifying respirators.
- ▶ Leave the area immediately if (1) while wearing a filter or cartridge respirator you can smell, taste, or otherwise detect **Sulfur Dioxide**, (2) while wearing particulate filters abnormal resistance to breathing is experienced, or (3) eye irritation occurs while wearing a full facepiece respirator. Check to make sure the respirator-to-face seal is still good. If it is, replace the filter or cartridge. If the seal is no longer good, you may need a new respirator.
- ▶ Consider all potential sources of exposure in your workplace. You may need a combination of filters, prefilters or cartridges to protect against different forms of a chemical (such as vapor and mist) or against a mixture of chemicals.
- ▶ Where the potential exists for exposure over **20 ppm**, use a NIOSH approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode. For increased protection use in combination with an auxiliary self-contained breathing apparatus or an emergency escape air cylinder.
- ▶ Exposure to **100 ppm** is immediately dangerous to life and health. If the possibility of exposure above **100 ppm** exists, use a NIOSH approved self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode equipped with an emergency escape air cylinder.

## SULFUR DIOXIDE

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### Fire Hazards

If employees are expected to fight fires, they must be trained and equipped as stated in the OSHA Fire Brigades Standard (29 CFR 1910.156).

- ▶ Extinguish fire using an agent suitable for type of surrounding fire. **Sulfur Dioxide** itself does not burn.
- ▶ POISONOUS GASES ARE PRODUCED IN FIRE, including *Sulfur Oxides*.
- ▶ CONTAINERS MAY EXPLODE IN FIRE.
- ▶ Use water spray to keep fire-exposed containers cool and to dilute and disperse vapors.

### Spills and Emergencies

If employees are required to clean-up spills, they must be properly trained and equipped. The OSHA Hazardous Waste Operations and Emergency Response Standard (29 CFR 1910.120) may apply.

If **Sulfur Dioxide** is leaked, take the following steps:

- ▶ Evacuate personnel and secure and control entrance to the area.
- ▶ Eliminate ignition sources.
- ▶ Ventilate area of leak to disperse the gas.
- ▶ Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty.
- ▶ Turn leaking cylinder with leak up to prevent escape of gas in liquid state.
- ▶ For *liquid* spills cover with dry lime, sand or soda ash and place into sealed containers for disposal.
- ▶ Ventilate area of *liquid* spill or leak.
- ▶ DO NOT wash into sewer.
- ▶ It may be necessary to contain and dispose of **Sulfur Dioxide** as a HAZARDOUS WASTE. Contact your state Department of Environmental Protection (DEP) or your regional office of the federal Environmental Protection Agency (EPA) for specific recommendations.

### Handling and Storage

Prior to working with **Sulfur Dioxide** you should be trained on its proper handling and storage.

- ▶ **Sulfur Dioxide** reacts violently with OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE); SODIUM HYDRIDE; and OTHER REDUCING AGENTS (such as LITHIUM, ZINC, ALUMINUM and their HYDRIDES).
- ▶ **Sulfur Dioxide** is not compatible with AMMONIA; BRASS; and COPPER.
- ▶ **Sulfur Dioxide** reacts with WATER or MOISTURE to form *Sulfuric Acid*.
- ▶ Store in tightly closed containers in a cool, well-ventilated area.

### Occupational Health Information Resources

The New Jersey Department of Health offers multiple services in occupational health. These services include providing informational resources, educational materials, public presentations, and industrial hygiene and medical investigations and evaluations.

#### For more information, please contact:

New Jersey Department of Health  
Right to Know  
PO Box 368  
Trenton, NJ 08625-0368  
Phone: 609-984-2202  
Fax: 609-984-7407  
E-mail: [rtk@doh.state.nj.us](mailto:rtk@doh.state.nj.us)  
Web address: <http://www.nj.gov/health/eoh/rtkweb>

*The Right to Know Hazardous Substance Fact Sheets are not intended to be copied and sold for commercial purposes.*



Right to Know Hazardous Substance Fact Sheet

**Emergency  
Responders  
Quick Reference**

Common Name: **SULFUR DIOXIDE**

Synonyms: Sulfurous Oxide; Sulfur Oxide

CAS No: 7446-09-5

Molecular Formula: SO<sub>2</sub>

RTK Substance No: 1759

Description: Colorless gas with a strong, irritating odor, that is often shipped as a liquid under pressure

HAZARD DATA		
Hazard Rating	Firefighting	Reactivity
<b>3 - Health</b> <b>0 - Fire</b> <b>0 - Reactivity</b> DOT#: UN 1079 ERG Guide #: 125 Hazard Class: 2.3 (Toxic gas)	Extinguish fire using an agent suitable for type of surrounding fire. <b>Sulfur Dioxide</b> itself does not burn. POISONOUS GASES ARE PRODUCED IN FIRE, including <i>Sulfur Oxides</i> . CONTAINERS MAY EXPLODE IN FIRE. Use water spray to keep fire-exposed containers cool and to dilute and disperse vapors.	<b>Sulfur Dioxide</b> reacts violently with OXIDIZING AGENTS (such as PERCHLORATES, PEROXIDES, PERMANGANATES, CHLORATES, NITRATES, CHLORINE, BROMINE and FLUORINE); SODIUM HYDRIDE; and OTHER REDUCING AGENTS (such as LITHIUM, ZINC, ALUMINUM and their HYDRIDES). <b>Sulfur Dioxide</b> is not compatible with AMMONIA; BRASS; and COPPER. <b>Sulfur Dioxide</b> reacts with WATER or MOISTURE to form <i>Sulfuric Acid</i> .

SPILL/LEAKS
<b>Isolation Distance:</b> Spill (small): 60 meters (200 feet) Spill (large): 400 meters (1,250 feet) Fire: 1,600 meters (1 mile) Stop flow of gas. If source of leak is a cylinder and the leak cannot be stopped in place, remove the leaking cylinder to a safe place in the open air, and repair leak or allow cylinder to empty. Turn leaking cylinder with leak up to prevent escape of gas in liquid state. Cover <i>liquid</i> spills with dry lime, sand or soda ash and place into sealed containers for disposal. DO NOT wash into sewer. <b>Sulfur Dioxide</b> is harmful to aquatic organisms.

PHYSICAL PROPERTIES
<b>Odor Threshold:</b> 0.3 to 5 ppm <b>Flash Point:</b> Nonflammable <b>Vapor Density:</b> 2.2 (air = 1) <b>Vapor Pressure:</b> 2,432 mm Hg at 68°F (20°C) <b>Specific Gravity:</b> 1.46 (water = 1) <b>Water Solubility:</b> Slightly soluble <b>Boiling Point:</b> 14°F (-10°C) <b>Melting Point:</b> -104°F (-76°C) <b>Critical Temp:</b> 315°F (157°C) <b>Ionization Potential:</b> 12.3 eV <b>Molecular Weight:</b> 64.07

EXPOSURE LIMITS
<b>OSHA:</b> 5 ppm, 8-hr TWA <b>NIOSH:</b> 2 ppm, 10-hr TWA, 5 ppm, STEL <b>ACGIH:</b> 0.25 ppm, 8-hr TWA <b>IDLH:</b> 100 ppm The Protective Action Criteria values are: PAC-1 = 0.2 ppm PAC-2 = 0.75 ppm PAC-3 = 30 ppm

PROTECTIVE EQUIPMENT
<b>Gloves:</b> Insulated Butyl and Neoprene (>4-hr breakthrough) <b>Coveralls:</b> Tychem® SL, BR, Responder® and TK (>8-hr breakthrough) <b>Respirator:</b> >0.25 ppm - full facepiece APR with cartridges specific for <b>Sulfur Dioxide</b> >20 ppm - SCBA

HEALTH EFFECTS
<b>Eyes:</b> Irritation and burns, contact with liquid may cause frostbite <b>Skin:</b> Irritation and burns, contact with liquid may cause frostbite <b>Inhalation:</b> Nose, throat and lung irritation, with coughing, and severe shortness of breath (pulmonary edema)

FIRST AID AND DECONTAMINATION
<b>Remove</b> the person from exposure. <b>Flush</b> eyes with large amounts of water for at least 15 minutes. Remove contact lenses if worn. Seek medical attention. <b>Immerse</b> affected part in warm water. Seek medical attention. <b>Begin</b> artificial respiration if breathing has stopped and CPR if necessary. <b>Transfer</b> promptly to a medical facility. <b>Medical</b> observation is recommended as symptoms may be delayed.

May 2010

## A.6.7: Nitrogen Dioxide



Common Name: **NITROGEN DIOXIDE**

CAS Number: 10102-44-0  
DOT Number: UN 1067

RTK Substance number: 1376  
Date: May 1989 Revision: April 2000

### HAZARD SUMMARY

- \* **Nitrogen Dioxide** can affect you when breathed in.
- \* **Nitrogen Dioxide** may cause mutations. Handle with extreme caution.
- \* Contact can irritate and burn the skin and eyes with possible eye damage.
- \* Breathing **Nitrogen Dioxide** can irritate the nose and throat.
- \* Breathing **Nitrogen Dioxide** can irritate the lungs causing coughing and/or shortness of breath. Higher exposures can cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath.
- \* High levels can interfere with the ability of the blood to carry *Oxygen* causing headache, fatigue, dizziness, and a blue color to the skin and lips (*methemoglobinemia*). Higher levels can cause trouble breathing, collapse and even death.
- \* Repeated exposure to high levels may lead to permanent lung damage.

### IDENTIFICATION

**Nitrogen Dioxide** is a dark brown to yellowish liquid or reddish-brown gas with a strong odor. It is used to produce other chemicals, as a nitrating and oxidizing agent, in bleaching flour, and in rocket fuels and explosives.

### REASON FOR CITATION

- \* **Nitrogen Dioxide** is on the Hazardous Substance List because it is regulated by OSHA and cited by ACGIH, DOT, NIOSH, DEP, HHAG, NFPA and EPA.
- \* Definitions are provided on page 5.

### HOW TO DETERMINE IF YOU ARE BEING EXPOSED

The New Jersey Right to Know Act requires most employers to label chemicals in the workplace and requires public employers to provide their employees with information and training concerning chemical hazards and controls. The federal OSHA Hazard Communication Standard, 1910.1200, requires private employers to provide similar training and information to their employees.

- \* If you think you are experiencing any work-related health problems, see a doctor trained to recognize occupational diseases. Take this Fact Sheet with you.
- \* Exposure to hazardous substances should be routinely evaluated. This may include collecting personal and area air samples. You can obtain copies of sampling results from your employer. You have a legal right to this information under OSHA 1910.1020.

### WORKPLACE EXPOSURE LIMITS

- OSHA: The legal airborne permissible exposure limit (PEL) is **5 ppm**, not to be exceeded at any time.
- NIOSH: The recommended airborne exposure limit is **1 ppm**, which should not be exceeded at any time.
- ACGIH: The recommended airborne exposure limit is **3 ppm** averaged over an 8-hour workshift and **5 ppm** as a STEL (short term exposure limit).

- \* **Nitrogen Dioxide** may cause mutations. All contact with this chemical should be reduced to the lowest possible level.

### WAYS OF REDUCING EXPOSURE

- \* Where possible, enclose operations and use local exhaust ventilation at the site of chemical release. If local exhaust ventilation or enclosure is not used, respirators should be worn.
- \* Wear protective work clothing.
- \* Wash thoroughly immediately after exposure to **Nitrogen Dioxide**.
- \* Post hazard and warning information in the work area. In addition, as part of an ongoing education and training effort, communicate all information on the health and safety hazards of **Nitrogen Dioxide** to potentially exposed workers.

## NITROGEN DIOXIDE

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This Fact Sheet is a summary source of information of all potential and most severe health hazards that may result from exposure. Duration of exposure, concentration of the substance and other factors will affect your susceptibility to any of the potential effects described below.

### HEALTH HAZARD INFORMATION

#### Acute Health Effects

The following acute (short-term) health effects may occur immediately or shortly after exposure to **Nitrogen Dioxide**:

- \* Contact can irritate and burn the skin and eyes with possible eye damage.
- \* Breathing **Nitrogen Dioxide** can irritate the nose and throat.
- \* Breathing **Nitrogen Dioxide** can irritate the lungs causing coughing and/or shortness of breath. Higher exposures can cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath.
- \* High levels can interfere with the ability of the blood to carry *Oxygen* causing headache, fatigue, dizziness, and a blue color to the skin and lips (*methemoglobinemia*). Higher levels can cause trouble breathing, collapse and even death.

#### Chronic Health Effects

The following chronic (long-term) health effects can occur at some time after exposure to **Nitrogen Dioxide** and can last for months or years:

#### Cancer Hazard

- \* **Nitrogen Dioxide** may cause mutations (genetic changes).
- \* There is no evidence that **Nitrogen Dioxide** causes cancer in animals. This is based on test results presently available to the New Jersey Department of Health and Senior Services from published studies.

#### Reproductive Hazard

- \* There is limited evidence that **Nitrogen Dioxide** may damage the developing fetus and decrease fertility in females.

#### Other Long-Term Effects

- \* Repeated exposure to high levels may lead to permanent lung damage.

### MEDICAL

#### Medical Testing

Before beginning employment and at regular times after that, the following are recommended:

- \* Lung function tests. These may be normal if the person is not having an attack at the time of the test.

If symptoms develop or overexposure is suspected, the following are recommended:

- \* Consider chest x-ray after acute overexposure.
- \* Blood methemoglobin level.

Any evaluation should include a careful history of past and present symptoms with an exam. Medical tests that look for damage already done are not a substitute for controlling exposure.

Request copies of your medical testing. You have a legal right to this information under OSHA 1910.1020.

#### Mixed Exposures

- \* Because smoking can cause heart disease, as well as lung cancer, emphysema, and other respiratory problems, it may worsen respiratory conditions caused by chemical exposure. Even if you have smoked for a long time, stopping now will reduce your risk of developing health problems.

### WORKPLACE CONTROLS AND PRACTICES

Unless a less toxic chemical can be substituted for a hazardous substance, **ENGINEERING CONTROLS** are the most effective way of reducing exposure. The best protection is to enclose operations and/or provide local exhaust ventilation at the site of chemical release. Isolating operations can also reduce exposure. Using respirators or protective equipment is less effective than the controls mentioned above, but is sometimes necessary.

In evaluating the controls present in your workplace, consider: (1) how hazardous the substance is, (2) how much of the substance is released into the workplace and (3) whether harmful skin or eye contact could occur. Special controls should be in place for highly toxic chemicals or when significant skin, eye, or breathing exposures are possible.

In addition, the following control is recommended:

- \* Where possible, automatically transfer gaseous **Nitrogen Dioxide** or pump liquid **Nitrogen Dioxide** from drums or other storage containers to process containers.

Good **WORK PRACTICES** can help to reduce hazardous exposures. The following work practices are recommended:

- \* Workers whose clothing has been contaminated by **Nitrogen Dioxide** should change into clean clothing promptly.
- \* Contaminated work clothes should be laundered by individuals who have been informed of the hazards of exposure to **Nitrogen Dioxide**.
- \* Eye wash fountains should be provided in the immediate work area for emergency use.
- \* If there is the possibility of skin exposure, emergency shower facilities should be provided.

## NITROGEN DIOXIDE

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- \* On skin contact with **Nitrogen Dioxide**, immediately wash or shower to remove the chemical. At the end of the workshift, wash any areas of the body that may have contacted **Nitrogen Dioxide**, whether or not known skin contact has occurred.
- \* Do not eat, smoke, or drink where **Nitrogen Dioxide** is handled, processed, or stored, since the chemical can be swallowed. Wash hands carefully before eating, drinking, smoking, or using the toilet.

### PERSONAL PROTECTIVE EQUIPMENT

WORKPLACE CONTROLS ARE BETTER THAN PERSONAL PROTECTIVE EQUIPMENT. However, for some jobs (such as outside work, confined space entry, jobs done only once in a while, or jobs done while workplace controls are being installed), personal protective equipment may be appropriate.

OSHA 1910.132 requires employers to determine the appropriate personal protective equipment for each hazard and to train employees on how and when to use protective equipment.

The following recommendations are only guidelines and may not apply to every situation.

#### Clothing

- \* Avoid skin contact with **Nitrogen Dioxide**. Wear acid-resistant gloves and clothing. Safety equipment suppliers/manufacturers can provide recommendations on the most protective glove/clothing material for your operation.
- \* All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

#### Eye Protection

- \* Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- \* Wear indirect-vent, impact and splash resistant goggles when working with liquids.
- \* Wear a face shield along with goggles when working with corrosive, highly irritating or toxic substances.

#### Respiratory Protection

##### IMPROPER USE OF RESPIRATORS IS DANGEROUS.

Such equipment should only be used if the employer has a written program that takes into account workplace conditions, requirements for worker training, respirator fit testing and medical exams, as described in OSHA 1910.134.

- \* Where the potential exists for exposure over **1 ppm**, use a MSHA/NIOSH approved supplied-air respirator with a full facepiece operated in a pressure-demand or other positive-pressure mode. For increased protection use in combination with an auxiliary self-contained breathing apparatus operated in a pressure-demand or other positive-pressure mode.

- \* Exposure to **20 ppm** is immediately dangerous to life and health. If the possibility of exposure above **20 ppm** exists, use a MSHA/NIOSH approved self-contained breathing apparatus with a full facepiece operated in a pressure-demand or other positive-pressure mode.

### HANDLING AND STORAGE

- \* Prior to working with **Nitrogen Dioxide** you should be trained on its proper handling and storage.
- \* **Nitrogen Dioxide** will react with WATER to form *Nitric Acid*.
- \* **Nitrogen Dioxide** may react explosively with TRIMETHYL TIN; TRIETHYLAMINE; AMMONIA; ALCOHOLS; ACETONITRILE; INDIUM; METHYL SULFOXIDE; HYDRAZINES; ALUMINUM POWDER; and CARBON DISULFIDE.
- \* **Nitrogen Dioxide** is not compatible with COMBUSTIBLE MATERIALS; CHLORINATED HYDROCARBONS; FORMALDEHYDE; FLUORINE; PETROLEUM; NITROBENZENE; COPPER; COPPER ALLOYS; and REDUCING MATERIALS.
- \* Store in tightly closed containers in a cool, dry, well-ventilated area.

### QUESTIONS AND ANSWERS

- Q: If I have acute health effects, will I later get chronic health effects?
- A: Not always. Most chronic (long-term) effects result from repeated exposures to a chemical.
- Q: Can I get long-term effects without ever having short-term effects?
- A: Yes, because long-term effects can occur from repeated exposures to a chemical at levels not high enough to make you immediately sick.
- Q: What are my chances of getting sick when I have been exposed to chemicals?
- A: The likelihood of becoming sick from chemicals is increased as the amount of exposure increases. This is determined by the length of time and the amount of material to which someone is exposed.
- Q: When are higher exposures more likely?
- A: Conditions which increase risk of exposure include physical and mechanical processes (heating, pouring, spraying, spills and evaporation from large surface areas such as open containers), and "confined space" exposures (working inside vats, reactors, boilers, small rooms, etc.).
- Q: Is the risk of getting sick higher for workers than for community residents?
- A: Yes. Exposures in the community, except possibly in cases of fires or spills, are usually much lower than those found in the workplace. However, people in the community may be exposed to contaminated water as well as to chemicals in the air over long periods. This

**NITROGEN DIOXIDE**

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may be a problem for children or people who are already ill.

Q: Can men as well as women be affected by chemicals that cause reproductive system damage?

A: Yes. Some chemicals reduce potency or fertility in both men and women. Some damage sperm and eggs, possibly leading to birth defects.

Q: Who is at the greatest risk from reproductive hazards?

A: Pregnant women are at greatest risk from chemicals that harm the developing fetus. However, chemicals may affect the ability to have children, so both men and women of childbearing age are at high risk.

Q: What are the likely health problems from chemicals which cause mutations?

A: There are two primary health concerns associated with mutagens: (1) cancers can result from changes induced in cells and, (2) adverse reproductive and developmental outcomes can result from damage to the egg and sperm cells.

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The following information is available from:

New Jersey Department of Health and Senior Services  
Occupational Health Service  
PO Box 360  
Trenton, NJ 08625-0360  
(609) 984-1863  
(609) 292-5677 (fax)

Web address: <http://www.state.nj.us/health/eoh/odisweb/>

**Industrial Hygiene Information**

Industrial hygienists are available to answer your questions regarding the control of chemical exposures using exhaust ventilation, special work practices, good housekeeping, good hygiene practices, and personal protective equipment including respirators. In addition, they can help to interpret the results of industrial hygiene survey data.

**Medical Evaluation**

If you think you are becoming sick because of exposure to chemicals at your workplace, you may call personnel at the Department of Health and Senior Services, Occupational Health Service, who can help you find the information you need.

**Public Presentations**

Presentations and educational programs on occupational health or the Right to Know Act can be organized for labor unions, trade associations and other groups.

**Right to Know Information Resources**

The Right to Know Infoline (609) 984-2202 can answer questions about the identity and potential health effects of chemicals, list of educational materials in occupational health, references used to prepare the Fact Sheets, preparation of the Right to Know Survey, education and training programs, labeling requirements, and general information regarding the Right to Know Act. Violations of the law should be reported to (609) 984-2202.  
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