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Reseach Article

Performance Analysis and Optimization of an Ammonia Stripper through Scrubber Integration Using Industrial Data and Aspen Hysys Simulation

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Abstract: The stripping gas from the ammonia stripper still shows fluctuating ammonia (NH_3) content and, under certain conditions, has the potential to exceed the targeted limit. This study discusses the evaluation of the ammonia stripper output gas and efforts to reduce NH_3 levels by adding a scrubber unit as a further treatment using Aspen HYSYS V.11 simulation. However, previous studies have primarily focused on ammonia removal within the stripper unit under steady-state conditions, with limited investigation into the integration of scrubber systems to handle fluctuating industrial wastewater and steam flow conditions. Operational performance was evaluated using industrial data collected during August 6–10, 2025, by calculating NH_3 removal efficiency based on inlet–outlet concentrations, followed by Aspen HYSYS simulation using the Extended NRTL model to analyze the effect of wastewater flow rate and assess the optimization process through scrubber integration. The evaluation results show that before the addition of the scrubber, the NH_3 reduction efficiency in the ammonia stripper was in the range of 87.78–96.34% with an average value of 92.97%, but under conditions of high wastewater discharge, the NH_3 concentration in the stripping gas still increased. Scrubber integration simulations showed that the NH_3 concentration in the stripper exhaust gas decreased from 3.21% to 0.96%, equivalent to a reduction of approximately 70%, indicating significant emission optimization. These results indicate that the addition of a scrubber to the stripped gas is an effective alternative to control NH_3 emissions.

Keywords: Ammonia Stripper, NH_3, Stripping Efficiency, Aspen HYSYS, Scrubber.

1. Introduction

Fertilizer is a key agricultural input that provides essential nutrients for plant growth and helps maintain soil fertility [1]. Nutrients may be supplied through organic or mineral fertilizers, with mineral fertilizers primarily providing nitrogen, phosphorus, and potassium, along with secondary and micronutrients. Globally, nitrogen, phosphorus, and potassium dominate fertilizer consumption, and urea is the most widely used nitrogen fertilizer, accounting for more than 50% of global nitrogen use [2]. Fertilizers are classified as single or compound products, with urea categorized as a single fertilizer containing approximately 46% nitrogen by weight [3]. The widespread use of urea and other ammonia-based fertilizers makes ammonia an essential component in fertilizer production while simultaneously increasing the potential generation of ammonia-containing waste streams.

The ammonia-based fertilizer industry plays a strategic role in supporting food security; however, ammonia plant operations generate process wastewater containing nitrogen compounds, particularly ammonia (NH_3), which is toxic to aquatic organisms and harmful to environmental quality if discharged without proper treatment. Due to its toxicity, ammonia discharge is regulated through strict environmental standards, including aquatic life criteria established by the United States Environmental Protection Agency (EPA), as well as national regulations such as Government Regulation No. 22 of 2021 and Minister of Environment Regulation No. 5 of 2014 in Indonesia, which define permissible ammonia concentrations in wastewater [4][5]. One of the key units commonly

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applied in ammonia-containing wastewater treatment systems is the Ammonia Stripper, which reduces dissolved ammonia through steam stripping prior to further treatment or discharge. Air stripping is widely recognized as an effective physicochemical method for ammonia removal and recovery, based on the phase transfer of volatile NH_3 from the liquid to the gas phase [6]. In practice, operating conditions often deviate from design specifications due to fluctuations in wastewater flow rate, influent ammonia concentration, and changes in temperature, pressure, and pH, which may reduce stripping efficiency. Recent studies confirm that stripping efficiency is strongly influenced by pH, temperature, and gas flow rate, as these parameters directly control ammonia volatilization and mass transfer performance. From a mass transfer perspective, the stripping process is governed by the volumetric mass transfer coefficient (K_la) and gas–liquid interfacial contact, which determine the rate of ammonia removal [7]. In addition, the stripping process produces ammonia-containing off-gas that requires further treatment using a scrubber to prevent air pollution.

The high concentration of NH_3 in liquid effluent and off-gas highlights the need for continuous evaluation and optimization of wastewater treatment units, as inadequate control may lead to environmental pollution, regulatory non-compliance, and disruption of sustainable fertilizer plant operation [8]. Recent reviews indicate that most ammonia removal studies focus on individual technologies, with limited evaluation of integrated systems under fluctuating industrial operating conditions. Therefore, this study evaluates the performance of the Ammonia Stripper based on NH_3 removal efficiency using actual operating data and Aspen HYSYS simulations. It also investigates process optimization through the installation of scrubbers to reduce NH_3 emissions so that both liquid and gaseous effluents meet environmental standards. This approach is expected to provide practical operational recommendations for improving ammonia wastewater treatment performance and supporting environmentally sustainable fertilizer production.

2. Research and Methodology

2.1 Block Diagram of Research Method

The research method in this calculation includes the collection and processing of several important data consisting of design data and actual field operation data. Design data includes steam influent conditions, such as temperature, pressure, and mass flow rate, as well as wastewater flow conditions, which include temperature, pressure, volumetric flow rate, and ammonia concentration. The actual data used includes the flow rate, temperature, and pressure of the steam influent, as well as the temperature, pressure, flow rate, and ammonia concentration in the wastewater flow, both on the influent and effluent sides.

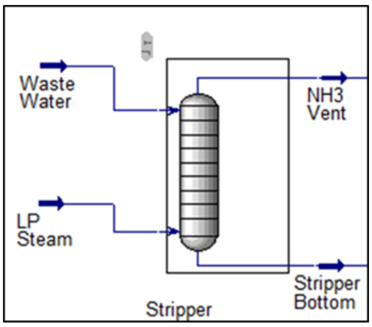


Figure 2.1. Ammonia Stripper Simulation in Aspen Hysys V.11

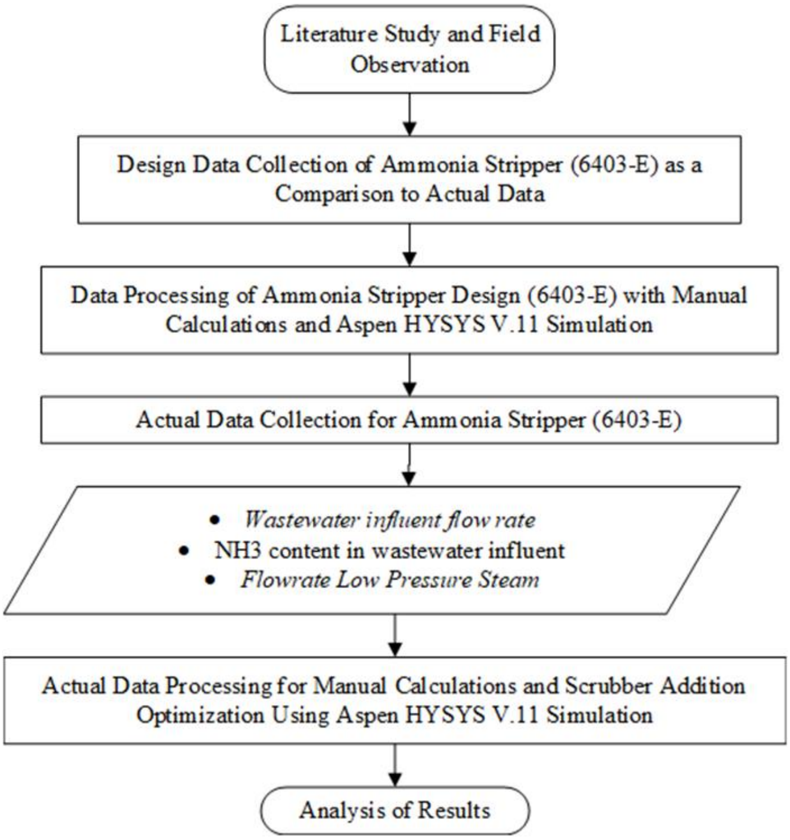


Figure 2.2. Data Processing Procedure Using Aspen Hysys V.11

2.2 Design Data and Actual Data

Design Data

Data	Temperature	Pressure	Flowrate	Composition
Waste Water	45 °C	1.97 kg/cm^{2}G	50 m^3 / h	NH_3 (100 ppm)
LP Steam	236 °C	3.5 kg/cm^2 G	13500 kg/h	100% H_2O

Actual Data

Data	Wastewater Flowrate (m^3/h)	Flowrate LP Steam (Ton/h)	NH_3 Influent (ppm)	NH_3 Effluent(ppm)
1	10	3.6	7592	278
2	10,2	3.5	4762	581
3	10	3.5	5440	378
4	10	3.6	5620	351
5	13,8	3.7	8325	614

2.3 Simulation Using Aspen HYSYS V.11

The first step in performing a simulation in ASPEN HYSYS V.11 is to create a new case. The components that must be entered are the compounds contained in the wastewater stream that will be processed in the Ammonia Stripper unit. The main compounds contained in the stream are ammonia (NH_3), water (H_2O), and sulfuric acid (H_2SO_4) as a scrubber agent, as well as ammonium sulfate as a product. The Extended NRTL model is an extension of the classic NRTL model for electrolyte systems. The Extended-NRTL was chosen because the components used consist of NH_3, H_2O, and H_2SO_4, which are electrolytes and undergo acid-base reactions. Extended NRTL is mainly used in the oil and gas industry to improve the accuracy of calculations in natural gas purification processes, especially in processes involving mixed solvents [9]. The feed consists of wastewater containing ammonia, which enters the column through the top as feed. Low pressure steam is fed into the bottom of the column to act as a stripping agent to help evaporate the ammonia from the liquid phase. The separation process produces two main products: the top product, which is a gas that exits through the NH_3 vent stream, and the bottom product, which is wastewater with reduced ammonia content that exits through the stripper bottom.

2.3. Ammonia Removal Efficiency (%)

Efficiency calculations are performed by subtracting the ammonia inlet from the outlet, then dividing by the inlet and multiplying by 100%. The ammonia removal efficiency (η) was calculated to evaluate the performance of the ammonia stripper in reducing NH_3 concentration in wastewater. This efficiency value was used to evaluate the performance of the ammonia stripper and to determine whether the effluent meets the required quality standard. The ammonia removal efficiency is calculated using the following equation:

$$\eta = \frac{Cin - \mathrm{Cout}}{Cin} \; x \; 100\ \% \tag{1}$$

Where :

η : Ammonia Removal Efficiency
C in : Ammonia Inlet Ammonia Stripper
C out : Ammonia Outlet Ammonia Stripper

This efficiency value was used to assess the effectiveness of the stripping process under different operating conditions and to determine whether the treated wastewater meets the required quality standards.

3. Results and Discussion

3.1 Efficiency of Ammonia Stripper Based on NH_3 Concentration Calculation Method

The presence of ammonia exceeding the threshold can disrupt aquatic ecosystems and other living creatures because it is toxic to almost all organisms [10]. In the Wastewater Treatment Unit in the fertilizer industry, ammonia strippers are the most important tool in reducing ammonia levels in liquid wastewater. The Ammonia Stripper works by reducing ammonia content using steam at the appropriate temperature and pressure. Based on the Regulation of the Minister of Environment (Permen LHK) No. 5 of 2014, the quality standard for ammonia levels in wastewater is 300 ppm.

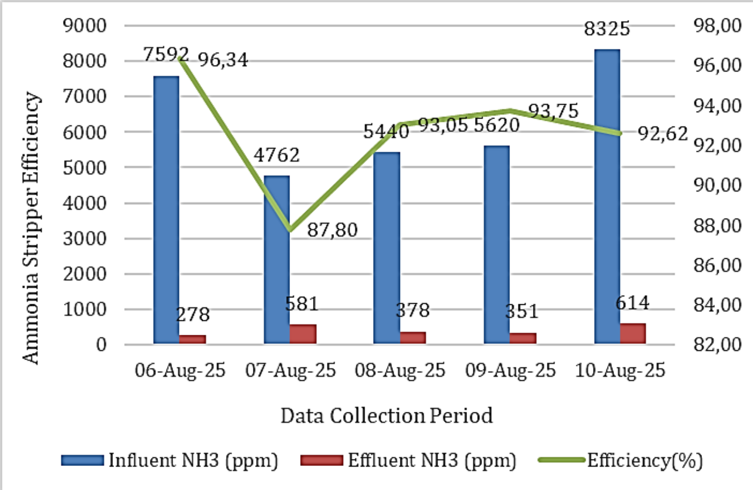


Figure 3.1. Ammonia Stripper Efficiency

Based on the results of the calculation of the efficiency of the Ammonia Stripper in the Wastewater Treatment System in the Utility Unit of a fertilizer industry during the period of August 6–10, 2025, the equipment performance showed less than optimal achievement with an average efficiency of 92.97%. This behavior can be explained by gas–liquid mass transfer mechanisms. In the ammonia stripping process, NH_3 is transferred from the liquid phase to the gas phase due to a concentration gradient between the bulk liquid and the equilibrium condition. The effectiveness of this transfer depends on the overall volumetric mass transfer coefficient (KLa) and the gas–liquid contact efficiency [11]. When operating conditions such as flow rate, temperature, or steam ratio are not optimal, the driving force for mass transfer decreases, resulting in lower ammonia removal efficiency.The daily efficiency range was between 87.78% and 96.34%, where the lowest efficiency decline occurred on August 7, which only reached 87.78%. The effluent data shows that on August 7–10, the ammonia content exceeded the quality standard so that the wastewater could not be directly discharged into the environment. This is influenced by load fluctuations or operating conditions such as pH, temperature, and a suboptimal air/steam ratio [12]. In addition, the equilibrium between ammonium ions (NH_4^+) and free ammonia (NH_3) plays a crucial role in the stripping process. At higher pH and temperature, the equilibrium shifts toward NH_3, which is more volatile and easier to remove. Therefore, suboptimal operating conditions may limit this equilibrium shift and reduce stripping performance.

Overall, the Ammonia Stripper reduces the NH_3 concentration in wastewater from an average of 6,748 ppm to 440 ppm. Ammonia Stripper performance can be said to be less than optimal if stripping is only performed once because the quality of the wastewater effluent does not meet quality standards. Wastewater that exceeds the quality standards will be reprocessed or circulated through the Stripper until the ammonia content is below 300 ppm, making the wastewater safe for discharge into the environment.

However, problems arise with gas emissions from stripping, as the success of this process actually transfers most of the NH_3 content to the gas phase, which is then released into the atmosphere. If the wind direction is directed towards residential areas, this condition has the potential to cause air pollution and trigger serious environmental problems, and even threaten the sustainability of plant operations [13]. Therefore, although the ammonia stripper's efficiency in wastewater treatment is considered good, further steps such as the addition of scrubbers are needed to control these emissions and ensure their safe release into the atmosphere.

3.2 Analysis of the Effect of Flowrate on Ammonia Stripper Using ASPEN HYSYS V.11

Based on the initial calculations, further simulations were conducted to analyze the effect of flow rate on the efficiency of the Ammonia Stripper using ASPEN HYSYS V11. The simulation was performed under controlled and observable conditions, with the steam flow rate assumed to be constant at 3.6 tons/h, based on the average value obtained from five data points. The influent NH_3 concentration was also assumed to remain constant at 6660 ppm, in accordance with the average measured values from the same five data points. The independent variable varied in the simulation was the wastewater flow rate, which was set at 5, 10, 15, 20, and 25 m³/h.

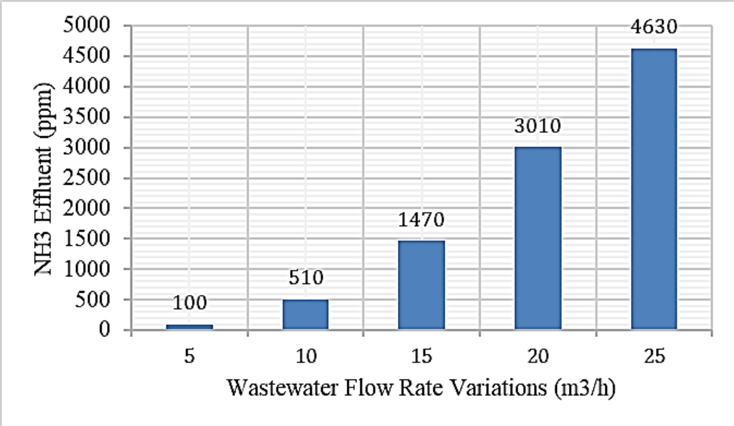


Figure 3.2. The Amount of NH3 Content in Effluent in Relation to Wastewater Flow Rate Variations

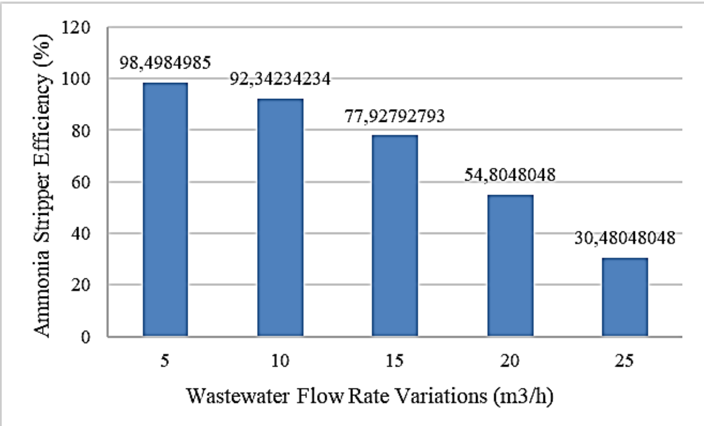


Figure 3.3. Ammonia Stripper Efficiency on Wastewater Flowrate Variations

Based on the simulation results shown in the graph, it can be seen that the greater the flow rate of wastewater entering the Ammonia Stripper, the more significantly the NH_3 content in the effluent increases, while its efficiency actually decreases. At a flow rate of 5 m³/h, the efficiency of the Ammonia Stripper reaches 98.49% with an effluent NH_3 content of only 100 ppm. However, when the flow rate is increased to 25 m³/h, the efficiency drops dramatically to 30.48% with an effluent NH_3 content of 4630 ppm. This shows that a high flow rate shortens the contact time between the liquid phase and the gas phase (steam), so that the mass transfer process of NH_3 from wastewater to the gas phase becomes suboptimal.

The efficiency of the Ammonia Stripper is greatly influenced by the ratio between the steam flow rate and the wastewater flow rate, where efficiency increases as the ratio of steam to wastewater increases [14]. This trend is consistent with previous studies, which reported that lower liquid-to-gas ratios significantly enhance ammonia removal efficiency and mass transfer rates due to increased stripping capacity and driving force. Similarly, other studies have shown that increasing the steam-to-wastewater ratio can improve ammonia removal efficiency from approximately 93% to over 99.9%, indicating the strong dependence of stripping performance on gas–liquid ratio [15]. This phenomenon can also be simplified through the working principle of the Ammonia Stripper itself, the greater the amount of steam (or stripping gas) flowing compared to the volume of wastewater, the greater the efficiency of ammonia transfer from the liquid phase to the gas phase. A high steam flow keeps the ammonia concentration in the gas phase low, thereby promoting a more effective movement (transition) of ammonia from wastewater to air [16]. These results also show that there is an optimum operating limit that must be considered. With a constant steam condition of 3.6 tons/hour, adequate stripping efficiency (≥80%) can be achieved at a maximum wastewater flow rate of around 14 m³/hour. If the wastewater discharge exceeds this value, an increase in the steam rate is required to maintain the ratio of steam to wastewater. Therefore, the control of Ammonia Stripper operations should not only refer to the liquid waste flow rate, but also consider the steam-to-wastewater ratio as a key parameter. This strategy can help maintain effluent quality to meet quality standards while optimizing energy use in the stripping system.

3.3 Changes in NH_3 Levels After Scrubber Addition in Aspen HYSYS V.11 Simulation

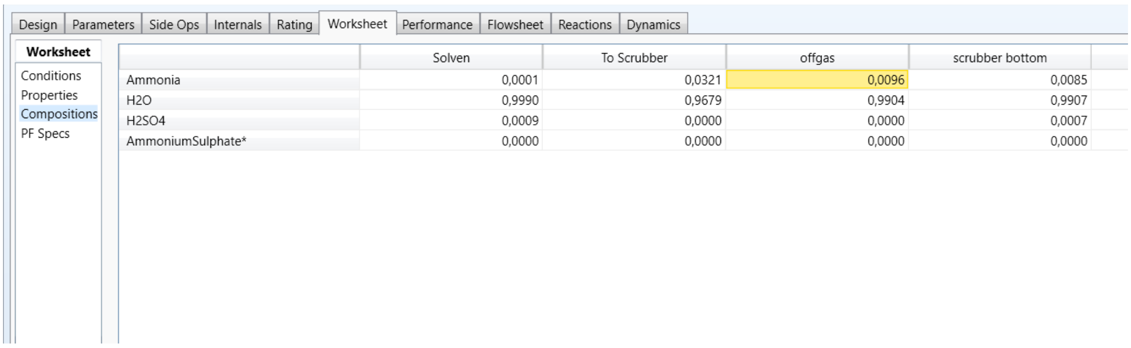
In this scrubber column, the aim is to capture ammonia (NH3) contained in the off-gas flow from the top of the Stripper column by using sulfuric acid solution (H2SO4) as the main capturing agent. Off-gas output from the top stripper containing significant amounts of ammonia will enter through the bottom scrubber and contact counter-currently with the sulfuric acid solution from the mixer so that chemical absorption occurs. The solvent liquid flow enters the column at a rate of 337.1 kmol/h at a temperature of 120.1 °C and a pressure of 199.4 kPa (vapor fraction = 0.0249), while the gas/feed flow to the scrubber is recorded at 122.5 Kmol/h at a temperature of 40 °C and a pressure of 100 kPa, so that the column produces 27.01 Kmol/h of off-gas and 432.6 kmol/h of bottom gas at a temperature of 76.3 °C and a pressure of 72.75 kPa.

Design | Parameters | Side Ops | Internals | Rating | Worksheet | Performance | Flowsheet | Reactions | Dynamics

Worksheet: Conditions, Properties, Compositions, PF Specs

Name	Solven @COL2	To Scrubber @COL2	offgas @COL2	scrubber bottom @COL2
Vapour	0,0249	0,0000	1,0000	0,0000
Temperature [C]	120,1	40,00	91,55	76,25
Pressure [kPa]	199,4	100,0	75,00	72,75
Molar Flow [kgmole/h]	337,1	122,5	27,01	432,6
Mass Flow [kg/h]	6098	2203	486,4	7814
Std Ideal Liq Vol Flow [m3/h]	6,096	2,249	0,4901	7,855
Molar Enthalpy [kJ/kgmole]	-2,772e+005	-2,767e+005	-2,369e+005	-2,795e+005
Molar Entropy [kJ/kgmole-C]	30,21	15,87	135,6	20,31
Heat Flow [kJ/h]	-9,343e+007	-3,390e+007	-6,400e+006	-1,209e+008

Figure 3.4 Conditions in the Scrubber Column



Design | Parameters | Side Ops | Internals | Rating | Worksheet | Performance | Flowsheet | Reactions | Dynamics

Worksheet
Conditions
Properties
Compositions
PF Specs

	Solven	To Scrubber	offgas	scrubber bottom
Ammonia	0,0001	0,0321	0,0096	0,0085
H2O	0,9990	0,9679	0,9904	0,9907
H2SO4	0,0009	0,0000	0,0000	0,0007
AmmoniumSulphate*	0,0000	0,0000	0,0000	0,0000

Figure 3.5. Composition in the Scrubber Column

Based on simulation results, the ammonia stripping process in the stripper unit was proven to significantly reduce ammonia levels in wastewater. The ammonia concentration in the liquid effluent decreased from 0.67% to around 0.01%, with a removal efficiency of ±98.5%. This indicates that the stripper is effective in separating ammonia from the liquid phase to the gas phase. However, the stripped gas (NH_3 vent) still contains a relatively high concentration of ammonia, around 3.21%, requiring further treatment. A relatively low concentration of H_2SO_4 solution, when optimized with appropriate scrubber design, is quite effective in reducing ammonia emissions [17]. Adding H_2SO_4 solution to the scrubber unit has been shown to reduce ammonia levels in the stripper gas to around 0.96%. In addition to reducing emissions and making it safer for release into the atmosphere, the scrubbing process also produces a valuable byproduct, ammonium sulfate ($(NH_4)_2SO_4$). Thus, the combination of ammonia stripper and scrubber can be said to be effective in improving the performance of waste treatment systems, while providing additional benefits in the form of utilizing by-products that are useful for the fertilizer industry.

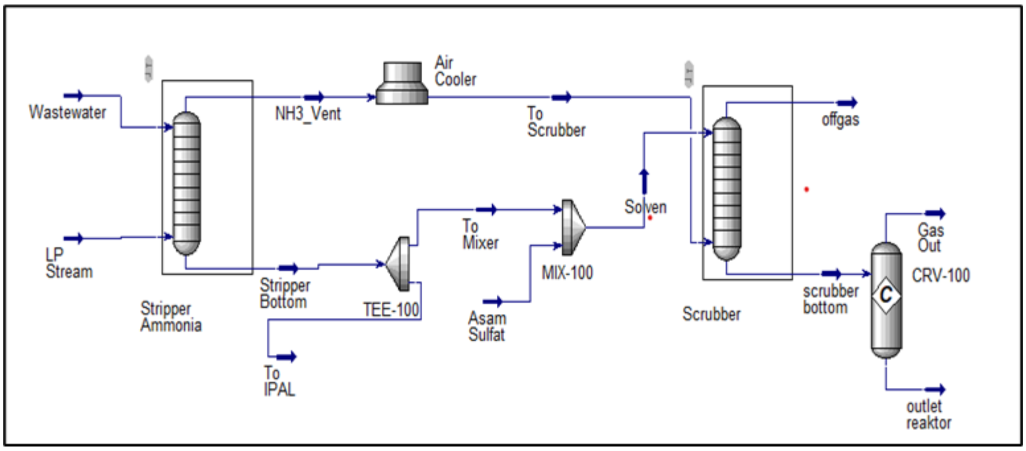


Figure 3.6. Overall Flowsheet in Aspen HYSYS V.11

4. Conclusion

Based on the evaluation results on the Ammonia Stripper and the addition of a scrubber, it can be concluded that the performance of the Ammonia Stripper in Waste Water Treatment unit is generally still able to reduce NH_3 levels significantly with an efficiency of 87.78–96.34% (average 92.97%). However, the quality of the stripping effluent still does not fully meet the quality standards, because the average effluent NH_3 content still reaches around 440 ppm so that re-stripping is necessary until the NH_3 level drops below 300 ppm. In addition, the efficiency of the Ammonia Stripper is greatly influenced by the ratio of steam flowrate to wastewater flowrate, where increasing the ratio of steam per wastewater can increase the effectiveness of the stripping process. Based on the results of the Aspen HYSYS V.11 simulation, the stripping gas still contains quite high levels of NH_3 so that a further unit in the form of a scrubber is needed. The addition of a scrubber using H_2SO_4 solution has been proven to be able to reduce the NH_3 content in the vent gas to around 0.96%, so that emissions are safer for the environment while producing a by-product in the form of ammonium sulfate ($(NH_4)_2SO_4$) which is useful for the fertilizer industry. The main contribution of this study is the integrated evaluation of ammonia stripping and scrubbing processes using actual industrial data and Aspen HYSYS simulation, demonstrating that scrubber addition effectively reduces NH_3 emissions and improves overall treatment performance. Further research is recommended to optimize scrubber operating parameters and to validate the simulation results through pilot-scale or industrial-scale experiments, including evaluation of economic and energy performance

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