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Optimizing Ammonia Recovery from Biogas Digestate Using Air Stripping: Experimental and Simulation Insights for Sustainable Waste Management

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ABSTRACT

The research aimed to determine the effectiveness of an ammonia recovery process through air stripping within biogas digestate. In the first step, the chicken manure was treated to volatilize the nitrogen in the form of ammonia, and then the resulting anaerobic centrate was stripped. Experimental tests and simulations with Aspen Plus were performed in order to understand the effect of temperature, flow rate, and pH on the ammonia as well as total nitrogen concentrations in the effluents.The results demonstrated that temperature, airflow rate, and pH had a significant influence on the ammonia stripping efficiency. Increasing the temperature from 30°C to 90°C improved the ammonium reduction from 80% to 93%, while increasing the airflow rate from 500 to 3000 kg/h enhanced the ammonium reduction from 75% to 97%. The pH had the most pronounced effect, with ammonium reduction increasing from 25% at pH 7.0 to 97% at pH 9.5.The Aspen Plus simulation model accurately predicted the experimental results, with a mean absolute percentage error below 3%. The model revealed the synergistic effects of pH and temperature, with optimal operating conditions identified at pH 9.0-9.5 and temperatures of 80-90°C. The results have proved to be helpful in the construction and improvement of how biogas digestate ammonia recovery systems are designed and built as well as the production of commercially valuable fertilizers whilst reducing the environmental pollution caused by nitrogen waste streams.

Keywords: Ammonia recovery, Nitrogen removal, Process simulations, Air stripping, Aspen Plus

INTRODUCTION

Biogas production from anaerobic digestion of organic waste streams, such as animal manure, is a promising approach for sustainable waste management (Alengebawy et al., 2024; Llanos-Lizcano et al., 2024). However, the resulting digestate is often rich in nitrogen, primarily in the form of ammonia, which can pose environmental challenges if not properly managed (Nagarajan et al., 2024; Abbà et al., 2023). Different treatment strategies for nitrogen recovery from digestate, such as ammonia stripping (Heidarzadeh Vazifehkhoran et al., 2022; Alhelal et al., 2022) and struvite precipitation (Ha et al., 2023; Astals et al., 2021), have distinct impacts on recovery efficiency and environmental implications. Ammonia stripping is effective in recovering nitrogen as ammonium sulfate, while struvite precipitation recovers nitrogen in the form of struvite, a slow-release fertilizer (Chojnacka & Chojnacki, 2024).

Air stripping technology is an effective method for recovering ammonia from digestate, converting it into ammonium sulfate, a valuable fertilizer (Yuan et al., 2024; Finzi et al., 2024). Key factors influencing efficiency include pH, temperature, and gas-to-liquid (G/L) ratios (Tao et al., 2024). Zhang et al. (2024) found that elevated pH levels increase the concentration of volatile free ammonia, enhancing recovery, with reported efficiencies of 88.5% at pH 9.5 for biogas slurry and 74.2% at pH 11.0 in gas-permeable membrane systems. Kim, Yu, and Chen (2022) reported that higher temperatures generally improve recovery, but in gypsum-based systems, efficiency decreased from 100% to 81% as the temperature rose from 20°C to 50°C, indicating complex interactions.

The airflow rate also affects ammonia transfer efficiency (Maghfiroh et al., 2022). An increase in air flow rate from 0 to 0.6 L/min significantly enhances the ammonia mass transfer coefficient from 1.21×10^{-7} m/s to 4.85×10^{-7} m/s, a 300% increase (Zhu et al., 2023). Additionally, lower CO_2 levels can enhance ammonia recovery efficiency (Kim, 2023; Palakodeti et al., 2022).

The integration of advanced simulation tools like Aspen Plus allows researchers to model the air stripping process, facilitating the prediction of outcomes and optimization of operational parameters to enhance both the economic and environmental performance of ammonia recovery systems (Li et al., 2020). Errico et al. (2017) utilized Aspen Plus to simulate a full-scale plant for ammonia recovery from biogas digestate. The process employed a stripper–absorber system with a flash drum to reduce buffer capacity, and NaOH was used to adjust the digestate to pH 9. Air at 90°C served as the stripping medium, and optimization of the airflow rate, including potential recycling, achieved a 95% ammonia recovery rate.

The widespread adoption of air stripping technology for ammonia recovery is limited by an incomplete understanding of the complex interactions among critical process parameters, such as temperature, pH, and airflow rate (Hu et al., 2024). This knowledge gap hampers optimization efforts and reduces process reliability. Furthermore, the absence of validated simulation models capable of accurately predicting system performance under varying operational conditions presents a major obstacle to designing and scaling efficient recovery systems (Ma, 2022; Sapkota et al., 2024). Overcoming these challenges is essential for developing cost-effective and stable air stripping processes that maximize ammonia recovery from biogas digestate.

Therefore, this study aims to systematically evaluate the efficiency of ammonia recovery from biogas digestate

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using an air stripping process. The specific objectives are to investigate the effects of temperature, airflow rate, and pH on ammonia and total nitrogen removal efficiencies. Additionally, the study seeks to develop and validate a simulation model using Aspen Plus to predict ammonia stripping performance under diverse operating conditions.

MATERIAL AND METHOD

Pre-treatment and Characterization of Chicken Manure

Chicken manure was pre-treated to release nitrogen as ammonia, primarily derived from proteins, before being used in the experiments. The manure was analyzed for its physical and chemical properties, revealing an average total solids (TS) content of 69% and a volatile solids (VS) content of 59%, measured following the standard SFS 3008. The moisture content was 31%, consistent with a dry matter proportion of 69%. The carbon-to-nitrogen (C/N) ratio was determined to be 9.6, reflecting a relatively high nitrogen content.

The pre-treatment process involved batching approximately 60 liters of chicken manure. The material was ground to prevent clogging, mixed with tap water, and supplemented with 10% (v/v) of a starter culture to create a slurry with a total solids content of 9%. The slurry was continuously stirred and subjected to anaerobic digestion at 55°C for 3 to 5 days in a closed 70-liter ammonification vessel. Following digestion, the effluent was centrifuged to separate suspended solids, producing an anaerobic centrate used for subsequent experiments..

Experimental Setup and Procedure

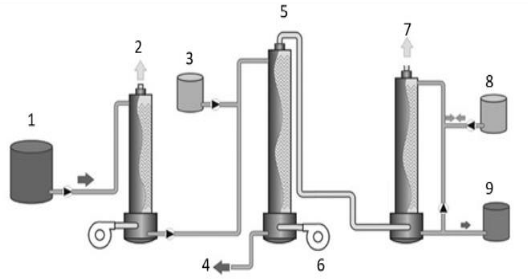
As shown in Figure 1, ammonia recovery from anaerobic centrate was conducted using a gas stripping process, which involved several key stages to efficiently remove ammonia from the digestate. Initially, the digestate was stored in a storage tank and underwent pretreatment in a CO_2 stripping column. This pretreatment removed carbon dioxide, reducing the buffer capacity of the digestate. To further enhance ammonia volatilization, sodium hydroxide (NaOH) was added to increase the pH, making ammonia more volatile and easier to strip. After pretreatment, the digestate was transferred into the main ammonia stripping column.

The stripping column was equipped with packing material to increase the surface area for gas-liquid mass transfer. A compressor provided air to facilitate ammonia transfer from the liquid phase to the gas phase. The ammonia-rich gas stream was then directed to a sorber column, where sulfuric acid (H_2SO_4) was dosed. This reaction with ammonia produced ammonium sulfate, a commercially valuable fertilizer.

A polyethylene stripping column with a diameter of 15 cm and a height of 190 cm was used for the ammonia removal experiments. The column was filled with 21.2 liters of Hel-X HX9 plastic carriers (Christian Stöhr GmbH&Co. KG, Germany), designed to maximize the surface area for mass transfer.

In the air stripping experimental apparatus, uninterrupted flows of liquid and air were sustained. 100 liters of anaerobic centrate were used in each experiment. The liquid flow rate was monitored using a calibrated flowmeter. The centrate was sprayed onto the packing carriers through a Lechler nozzle to ensure optimal contact between the liquid and air phases. Air was supplied by a blower, with adjustable flow rates between 500 and 3000 kg/hr, measured by a flowmeter. The air was preheated using a hot air blower.

After each experiment, the effluent was analyzed for ammonium, and total nitrogen to evaluate the efficiency of ammonia removal. The study systematically examined the effects of varying operational parameters, such as



1-Digestate Storage 2-Stripping of CO2 3-Addition of base (Na OH)
4-Outlet (Stripped digestate) 5-Column for stripping of NH3
6-Blower for stripping air 7-Sorber column 8-Dosing of acid (H2SO4)
9- Storage for ammonium sulphate

Fig. 1. System diagram of the experimental setup. (Source: Fuchs and Drosg, 2010)

Model Description and Simulation Framework

The study utilized the Aspen Plus software package to model and simulate the ammonia recovery process from biogas digestate by air stripping. The process flowsheet of the simulation model is depicted in Fig. 2. The selection of an appropriate thermodynamic model is essential to accurately predict the non-ideality of the liquid digestate system. In this study, the electrolyte non-random two-liquid (ENRTL) model and the Redlich–Kwong (RK) cubic equation of state were employed to determine the gas–liquid equilibrium and electrolyte properties. These models are specifically applicable to the CO_2–NH_3–H_2O system within a temperature range of 0–100 °C, pressures up to 16 bar, and concentrations up to 23 mol/L of NH_3 and 8 mol/L of CO_2. The ENRTL model accounts for the interactions between ions and molecules in the liquid phase, while the RK equation of state provides a reliable estimation of gas-phase properties. These models facilitate the prediction of both vapor–liquid and chemical equilibrium constants, which are crucial for the accurate simulation of the studied system and its operational conditions.

Air stripping is employed to transfer ammonia from the liquid phase to the gas phase, which is subsequently contacted with a sulfuric acid solution. This facilitates the transfer of ammonia into a secondary liquid phase, where it reacts with sulfuric acid. The process is conducted at elevated temperatures to enhance efficiency.

To reduce the buffering effect of CO_2 and increase the pH of the incoming digestate, the integration of a flash drum prior to the stripping column is proposed to remove CO_2. Sodium hydroxide (NaOH) is then added after the flash drum to promote the formation of ammonia over ammonium. The process flowsheet is depicted in Fig. 1. In this process, 20,000 kg/h of feed digestate at an initial temperature of 20 °C and a pressure of 1.6 atm is heated to 90 °C using a gas-fired heater. Subsequently, the pressure is reduced to 1 atm, and CO_2 is removed in the flash drum. The resulting liquid stream is then mixed with NaOH and introduced into the stripping column.

To address the potential for fouling caused by insoluble fibers present in the reject stream, a randomly packed column equipped with plastic packing is utilized. This design choice ensures resistance to clogging and corrosive chemicals. For the purposes of this analysis, fouling effects are otherwise considered negligible. The assumptions utilized in the model are detailed in Table 1.

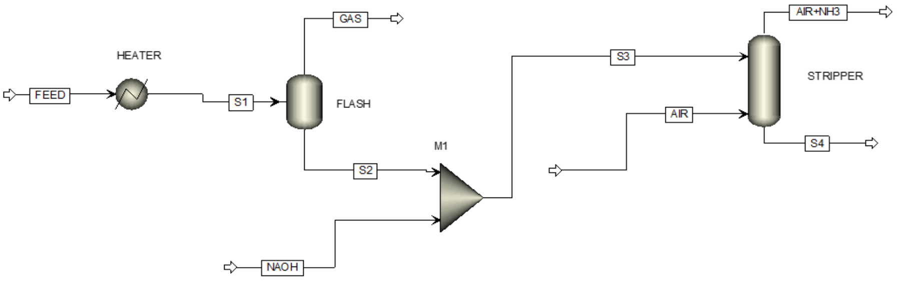


Fig.2. The process flowsheet of the simulation model

Table 1. Assumptions Used in the Model

Assumptions	Description
Digestate Composition	– Digestate consists solely of dissolved salts, with solids and other soluble molecules neglected..
Charge Balance	– Chemical composition is adjusted to ensure electrical neutrality, required for simulation
Equilibrium Reactions	– Both acid/base and vapor/liquid equilibrium reactions are included to describe the system's chemical behavior
pH and Temperature Dependency	– pH is calculated from hydronium ion concentration; equilibrium is temperature-dependent
Air Composition	– Air is modeled with a fixed composition: 76.754% N_2, 23.2% O_2, and 0.046% CO_2
Separation Feasibility	– Components are separable if their relative volatility (α) is greater than 1.
Equipment Fouling	– Fouling and non-idealities in equipment or gas/liquid behavior are neglected for simplicity.
Thermodynamic Basis	– All calculations assume equilibrium conditions, with Aspen Plus software used for simulation.
Ideal Conditions Assumption	– Non-idealities (e.g., deviations from ideal gas behavior) are ignored for simplifying the model.

RESULTS AND DISCUSSIONS

Effect of Operating Temperature on Ammonium and Total Nitrogen Removal

As shown in Figure 3, The effect of temperature on ammonia stripping efficiency was investigated at different temperatures (30-90°C) while maintaining a constant pH of 9.0 and an air flow rate of 2000 kg h^{-1}. The experimental results demonstrated that temperature significantly influenced both ammonium and total nitrogen reduction rates. At 30°C, the ammonium reduction efficiency was 80 ± 1%, which progressively increased to 93 ± 2% at 90°C. Similarly, total nitrogen reduction showed an upward trend, starting at 66 ± 2% at 30°C and reaching 87 ± 1% at 90°C.

The experimental results clearly demonstrate the positive correlation between temperature and nitrogen removal efficiency. The enhancement in removal efficiency with increasing temperature can be attributed to the improved mass transfer coefficient at higher temperatures, which facilitates better ammonia stripping. This trend aligns with Henry's law, where higher temperatures favor the transfer of ammonia from the liquid to the gas phase. Ammonium reduction consistently showed higher values compared to total nitrogen reduction across all temperatures, with the difference between the two remaining relatively constant (12-14%), indicating stable process dynamics. The lower removal efficiency of total nitrogen compared to ammonium may be attributed to the presence of other nitrogen forms in the anaerobic reactor, which are not impacted by the stripping process. The highest removal efficiencies were achieved at 90°C, with 93 ± 2% for ammonium and 87 ± 1% for total nitrogen.

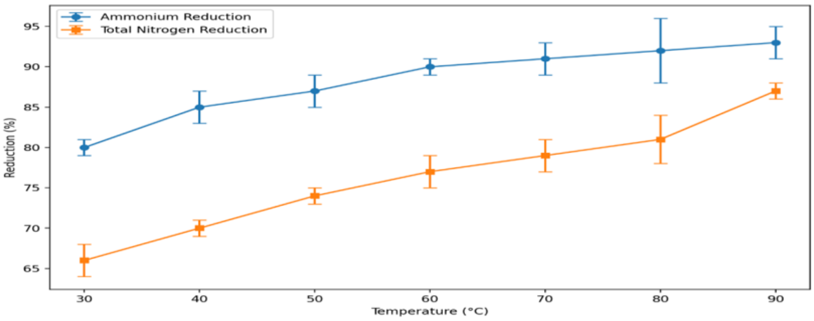


Fig. 3. Effect of temperature on ammonium and total nitrogen reduction efficiency During ammonia Stripping at pH 9 and air Flow Rate of 2000 kg h^{-1}

However, a notable observation is the diminishing returns in removal efficiency above 70°C. The rate of improvement in reduction efficiency becomes less pronounced in the temperature range of 70-90°C, suggesting that operating temperatures between 70-80°C might offer an optimal balance between removal efficiency and energy consumption. The small error bars (±1-4%) across all measurements indicate good reproducibility and reliability of the experimental data, further supporting the validity of the observed trends. These findings suggest that while maximum removal efficiency is achieved at 90°C, the optimal operating temperature might be lower when considering energy requirements and operational costs.

Effect of Air Flow Rate on Ammonium and Total Nitrogen Removal

As shown in Figure 4, The effect of airflow rate on ammonia stripping efficiency was investigated at different air flow rates (500-3000 kg/hr) while maintaining a constant pH of 9.0 and a temperature of 80°C. The experimental results demonstrated that airflow rate significantly influenced both ammonium and total nitrogen reduction rates. At the lowest airflow rate of 500 kg/hr, the ammonium reduction efficiency was 75 ± 3%, which progressively increased to 97 ± 3% at the highest airflow rate of 3000 kg/hr. Similarly, Total nitrogen reduction showed an upward trend, starting at 69 ± 3% at 500 kg/hr and reaching 89 ± 2% at 3000 kg/hr.

The experimental results clearly demonstrate the positive correlation between airflow rate and nitrogen removal efficiency. The enhancement in removal efficiency with increasing airflow rate can be attributed to improved mass transfer dynamics, where higher airflow rates enhance the stripping of ammonia from the liquid phase. Ammonium reduction consistently showed higher values compared to total nitrogen reduction across all airflow rates, with the difference between the two remaining relatively constant (6-8%), indicating stable process dynamics. The highest removal efficiencies were achieved at 3000 kg/hr, with 97 ± 3% for ammonium and 89 ± 2% for total nitrogen.

However, a notable observation is the diminishing returns in removal efficiency at higher airflow rates. The rate of improvement in reduction efficiency becomes less pronounced in the range of 2500-3000 kg/hr, suggesting that operating airflow rates between 2000-2500 kg/hr might offer an optimal balance between removal efficiency and energy consumption. The small error bars (±1-3%) across all measurements indicate good reproducibility and reliability of the experimental data, further supporting the validity of the observed trends. These findings suggest that while maximum removal efficiency is achieved at 3000 kg/hr, the optimal operating air flow rate might be lower when considering energy requirements and operational costs.

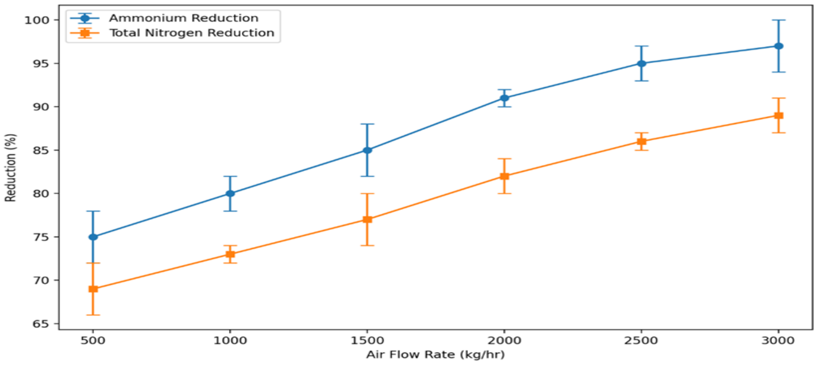


Fig. 4 Effect of air flow rate on ammonium and total nitrogen reduction efficiency During ammonia Stripping at pH 9 and and temperature 80 °C

Effect of pH on Ammonium and Total Nitrogen Removal

As shown in Figure 5, The effect of pH on ammonia stripping efficiency was investigated at different pH levels (7.0-9.5) while maintaining a constant temperature of 80°C and an air flow rate of 2000 kg h^{-1}. The experimental results demonstrated that pH significantly influenced both ammonium and total nitrogen reduction rates. At the lowest pH of 7.0, the ammonium reduction efficiency was 25 ± 2%, which progressively increased to 97 ± 1% at the highest pH of 9.5. Similarly, Total nitrogen reduction showed an upward trend, starting at 21 ± 1% at pH 7.0 and reaching 87 ± 4% at pH 9.5.

The experimental results clearly demonstrate the positive correlation between pH and nitrogen removal efficiency. The enhancement in removal efficiency with increasing pH can be attributed to the increased availability of free ammonia (NH_3) at higher pH levels, which facilitates better stripping from the liquid phase. Ammonium reduction consistently showed higher values compared to total nitrogen reduction across all pH levels, with the difference between the two remaining relatively constant (4-6%), indicating stable process dynamics. The highest removal efficiencies were achieved at pH 9.5, with 97 ± 1% for ammonium and 87 ± 4% for total nitrogen.

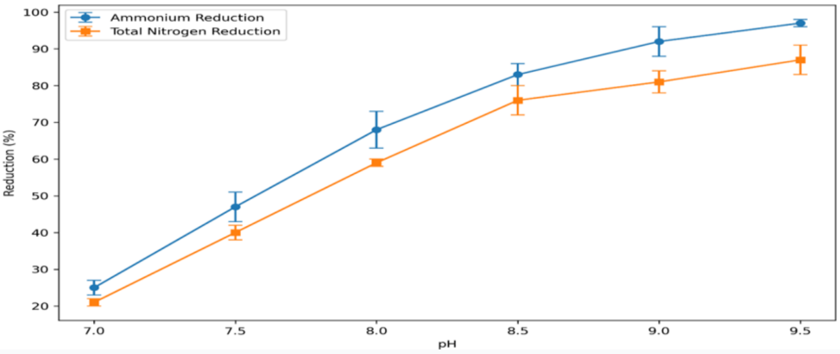


Fig. 5. Effect of pH on ammonium and total nitrogen reduction efficiency During ammonia Stripping at air Flow Rate of 2000 kg $h^{-1}$and temperature 80 °C

However, a notable observation is the diminishing returns in removal efficiency at higher pH levels. The rate of improvement in reduction efficiency becomes less pronounced in the range of pH 9.0-9.5, suggesting that operating at pH 9.0 might offer an optimal balance between removal efficiency and chemical usage. The small error bars

(±1-4%) across all measurements indicate good reproducibility and reliability of the experimental data, further supporting the validity of the observed trends. These findings suggest that while maximum removal efficiency is achieved at pH 9.5, the optimal operating pH might be slightly lower when considering chemical costs and operational feasibility.

Simulation of Ammonium Removal at Different Temperatures, pH Levels, and Air Flow Rates

As shown in Figure 6, The effect of pH and temperature on ammonia stripping efficiency was investigated using Aspen Plus simulation at different pH levels (6.0-9.5) and temperatures (60-90°C), maintaining a constant air flow rate of 2000 $kg\ h^{-1}$. The simulation results demonstrated that both pH and temperature significantly influenced the ammonium reduction efficiency. At 60°C, the ammonium reduction efficiency increased from 0% at pH 6.0 to 97% at pH 9.5. Similar trends were observed at higher temperatures, with enhanced reduction efficiencies. The highest reduction efficiencies of 100% were achieved at 80°C and 90°C when operating at pH 9.5.

The simulation results reveal several important insights into the ammonia stripping process. First, there is a clear synergistic effect between pH and temperature on ammonium reduction efficiency. The impact of pH on reduction efficiency can be attributed to the chemical equilibrium between ammonium (NH_4) and free ammonia (NH_3), which is strongly pH-dependent. As pH increases, the equilibrium shifts towards free ammonia, facilitating better stripping efficiency. Temperature effects are particularly notable in the results. At 60°C, while the process achieves good reduction efficiency (97% at pH 9.5), increasing the temperature to 80-90°C allows for complete or near-complete ammonium reduction (100%) at the same pH. This enhancement can be explained by two mechanisms: increased mass transfer coefficients at higher temperatures and shifted chemical equilibrium favoring free ammonia formation.

The data shows distinct performance regions across the pH spectrum. At pH values below 7.0, the reduction efficiency is limited (0-14%) across all temperatures, indicating insufficient free ammonia availability. In the pH range of 7.0-8.0, moderate reduction efficiency is observed with strong temperature dependence, where the reduction efficiency ranges from 14-70% at 60°C and increases to 30-80% at 90°C. At pH values above 8.0, high reduction efficiency is achieved, with optimal performance exceeding 90% reduction above pH 9.0 for all temperatures. A notable observation is the diminishing returns in reduction efficiency at higher pH levels, particularly above pH 9.0. While maximum reduction efficiency is achieved at pH 9.5, the marginal improvement from pH 9.0 to 9.5 is relatively small (5-8% increase), suggesting that operating at pH 9.0 might be more economically viable when considering chemical costs.

Temperature effects become more pronounced in the mid-pH range of 7.5-8.5, where increasing temperature from 60°C to 90°C can improve reduction efficiency by 20-25 percentage points. This suggests that temperature optimization might be more critical in systems operating at moderate pH levels. However, at very high pH values above 9.0, the temperature effect becomes less significant, indicating that pH is the dominant factor in these conditions. These findings have important implications for process design and optimization in industrial applications. The simulation results suggest that optimal operating conditions would be at pH 9.0-9.5 and temperatures of 80-90°C for maximum efficiency. For energy efficiency, operating at pH 9.0 and 80°C achieves 95% reduction, while for moderate treatment requirements, operating at pH 8.5 and 70-80°C achieves 83-85% reduction.

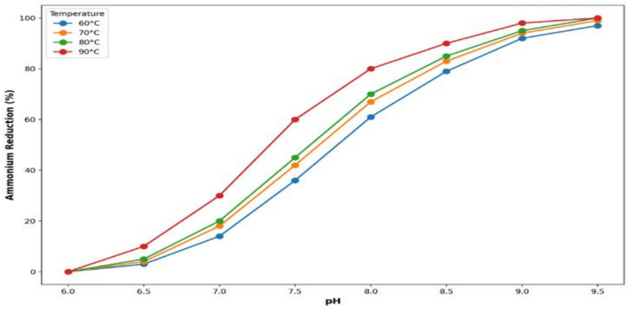


Fig. 6 Effect of pH and temperature on ammonium reduction efficiency During ammonia Stripping at air Flow Rate of 2000 $kg\ h^{-1}$

As shown in Figure 7, The effect of airflow rate on ammonia stripping efficiency was investigated using Aspen Plus simulation at different air flow rates (500-4000 kg/h) and temperatures (60-90°C), maintaining a constant pH of 9. The simulation results demonstrated that both airflow rate and temperature significantly influenced the ammonium reduction efficiency. At the lowest temperature of 60°C, the ammonium reduction efficiency increased from 75% at 500 kg/h to 95% at 3500 kg/h, with no further improvement at 4000 kg/h. Similar trends were observed at higher temperatures, with enhanced reduction efficiencies. The highest reduction efficiency of 99% was achieved at 90°C with airflow rates of 3000 kg/h and above.

The simulation results reveal important insights into the ammonia stripping process optimization. A clear correlation exists between airflow rate and ammonium reduction efficiency, with the relationship showing a characteristic logarithmic pattern. The reduction efficiency increases rapidly at lower air flow rates (500-2000 kg/h) before gradually plateauing at higher flow rates, suggesting a diminishing returns effect.

Temperature plays a crucial role in enhancing the stripping efficiency across all airflow rates. At 60°C, the maximum achievable reduction was 95%, while at 90°C, the process achieved 99% reduction. The enhanced performance at higher temperatures can be attributed to increased mass transfer coefficients and higher vapor pressure of ammonia, which facilitates better stripping efficiency. The synergistic effect between temperature and air flow rate is particularly evident in the mid-range flow rates (1500-2500 kg/h), where higher temperatures show steeper improvement curves.

The data reveals that the process becomes increasingly efficient with higher temperatures, particularly in the lower airflow rate range. For instance, at 500 kg/h, increasing the temperature from 60°C to 90°C improved the reduction efficiency from 75% to 78%. However, this temperature effect becomes less pronounced at higher airflow rates, suggesting that increased air flow can partially compensate for lower operating temperatures.

An important observation is the existence of optimal operating points beyond which further increases in air flow rate yield minimal improvements. For all temperatures, the reduction efficiency curves begin to plateau around 3000-3500 kg/h. This plateau effect is most pronounced at higher temperatures, where 90°C achieves 99% reduction at 3000 kg/h with no significant improvement at higher flow rates. This suggests that operating beyond these flow rates would increase energy costs without proportional benefits in reduction efficiency.

For optimal economic operation, the results suggest operating at moderate to high temperatures (80-90°C) with air flow rates around 3000 kg/h, as this provides near-maximum reduction efficiency without excessive air flow requirements. Utilizing a lower reduction efficiency approach, it is possible to operate at a temperature between (60-70°C) with a moderate airflow of (2000-2500 kg/h), while still achieving an efficiency of 85-90%. This approach is more energy efficient.

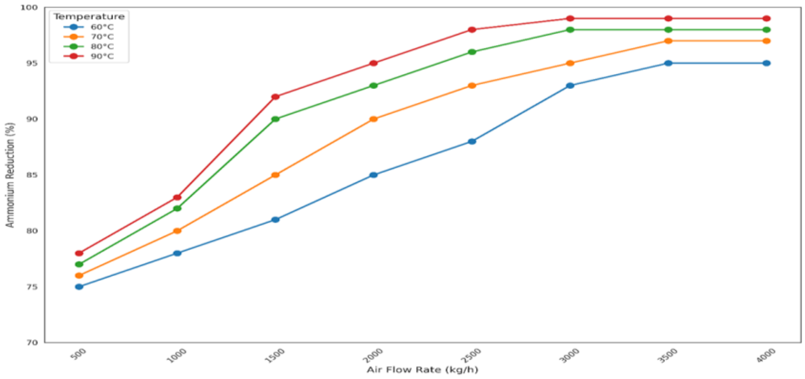


Fig. 7. Effect of air flow rate and temperature on ammonium reduction efficiency During ammonia Stripping at at pH 9

Validation of Simulation Results Against Experimental Data

As shown in Figure 8 and Figure 9, the validation of the Aspen Plus simulation model was conducted through systematic comparison with experimental data across two critical operational parameters: air flow rate and pH. For airflow rate variations (500-3000 kg h^{-1}), the model demonstrated excellent predictive accuracy with a mean absolute percentage error (MAPE) below 3%. At lower air flow rates (500 kg h^{-1}), the simulation predicted 77% reduction compared to the experimental value of 75%, while at maximum flow rate (3000 kg h^{-1}), the model predicted 98% reduction versus the experimental result of 97%.

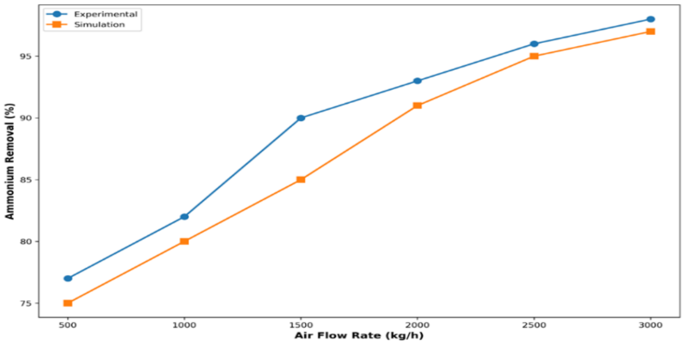


Fig. 8. Effect of air flow rate on ammonium reduction efficiency During ammonia Stripping at pH 9 and and temperature 80 °C

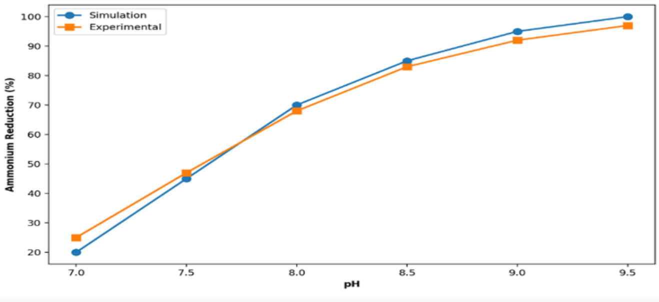


Fig. 9 Effect of pH on ammonium reduction efficiency During ammonia Stripping at temperature 80 °C and air Flow Rate of 2000 kg h^{-1}

Similarly, for pH-dependent studies (pH 7.0-9.5), the simulation model exhibited strong correlation with experimental data ($R^2 > 0.95$). The model accurately captured the increasing trend in reduction efficiency with pH elevation, showing slight underestimation at lower pH (20% simulated vs. 25% experimental at pH 7.0) and minor overestimation at higher pH (100% simulated vs. 97% experimental at pH 9.5). These deviations fall within acceptable statistical margins for process modelling.

The comprehensive validation analysis confirms the robustness of the Aspen Plus simulation model for predicting ammonia stripping performance under varying operational conditions. The close agreement between simulated and experimental results, particularly at optimal operating conditions (airflow rates 2500-3000 kg h^{-1} and pH > 9.0), validates the model's reliability for process design and optimization applications. The minor discrepancies can be attributed to experimental uncertainties and inherent limitations in modeling complex mass transfer phenomena.

CONCLUSION

This study systematically evaluated the effects of temperature, airflow rate, and pH on ammonium and total nitrogen removal via ammonia stripping, combining actual trials with Aspen Plus simulations. The findings demonstrate that removal efficiencies improve significantly with increasing temperature, airflow rate, and pH, with optimal results observed at 80–90°C, airflow rates of 2000–3000 kg/h, and pH levels of 9.0–9.5. However, diminishing returns were noted at higher ranges of these parameters, emphasizing the need to balance efficiency with energy and operational costs.

Simulations validated experimental results, achieving near-complete ammonium reduction (99–100%) under optimal conditions. The high correlation between simulated and experimental data (MAPE < 3%) underscores the reliability of the model for process design and optimization. These findings provide a robust framework for optimizing ammonia stripping processes, ensuring enhanced efficiency and cost-effectiveness for industrial applications.

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تحسين استرجاع الأمونيا من مخلفات الهضم الحيوي باستخدام تقنية التجريد الهوائي: رؤى تجريبية ومحاكاة لإدارة مستدامة للنفايات

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الملخص

هدفت الدراسة إلى تحقيق الكفاءة في استرجاع الأمونيا من مخلفات الهضم الحيوي باستخدام عملية التجريد الهوائي. تم معالجة سماد الدجاج مسبقًا لتحرير النيتروجين على شكل أمونيا، ثم تعرض السائل الناتج من عملية الهضم اللاهوائي لعملية تجريد غازية. تم دراسة تأثير عوامل التشغيل، مثل درجة الحرارة، ومعدل تدفق الهواء، ودرجة الحموضة، على كفاءة إزالة الأمونيا والنيتروجين الكلي بشكل منهجي من خلال التجارب والمحاكاة باستخدام برنامج Aspen Plus.ظهرت النتائج أن درجة الحرارة، ومعدل تدفق الهواء، ودرجة الحموضة لها تأثير كبير على كفاءة تجريد الأمونيا. حيث أدى رفع درجة الحرارة من 30 درجة مئوية إلى 90 درجة مئوية إلى زيادة تقليل الأمونيوم من 80% إلى 93%، بينما أدى زيادة معدل تدفق الهواء من 500 إلى 3000 كجم/ساعة إلى تحسين تقليل الأمونيوم من 75% إلى 97%. كان لدرجة الحموضة التأثير الأكثر وضوحًا، حيث زادت نسبة تقليل الأمونيوم من 25% عند درجة حموضة 7.0 إلى 97% عند درجة حموضة 9.5.قدّم نموذج المحاكاة باستخدام Aspen Plus نتائج دقيقة للغاية مقارنةً بالتجارب العملية، حيث بلغ متوسط نسبة الخطأ المطلق أقل من 3 %. وكشف النموذج عن التأثيرات التفاعلية بين الأس الهيدروجيني ودرجة الحرارة، مع تحديد الظروف التشغيلية المثلى عند pH بين 9.0 و 9.5 ودرجات حرارة بين 80 و 90 درجة مئوية .توفر هذه النتائج رؤى قيمة لتصميم وتحسين أنظمة استرداد الأمونيا من السوائل الناتجة عن الهضم اللاهوائي، مما يساهم في إنتاج سماد تجاري عالي القيمة مع تقليل التأثير البيئي للنفايات الغنية بالنيتروجين.