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Evaluation of Ammonia Removal from Industrial Wastewater Using Air Stripping and Wet Air Oxidation Methods

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1. ABSTRACT

The presence of ammonia in petrochemical wastewater represents a significant environmental challenge. In this study, two methods—stripping with air flow and wet air oxidation (WAO)—for ammonia removal were simulated and analyzed using Aspen Plus software. After simulating the processes based on experimental data and industrial operating conditions, the models were validated with data from previous studies. The thermodynamic model ENRTL-RK was used in the process simulation. Both methods showed acceptable efficiency in terms of nitrogen recovery. The WAO method, with an ammonia removal efficiency of 98.53%, demonstrated superior performance compared to the stripping method, which achieved an ammonia removal efficiency of 92.90%. However, the WAO method requires more complex operating conditions and higher energy consumption. Despite its lower efficiency, the stripping method is considered a suitable option for industrial applications in many cases, especially under technological limitations, due to its operational simplicity, low cost, and ease of implementation.

Keywords: Air Stripping, Wet Air Oxidation, Ammonia Removal, Industrial Wastewater, Aspen Plus.

2. INTRODUCTION

Ammonia is one of the most critical nitrogenous pollutants commonly found in industrial effluents, particularly from fertilizer production units, refineries, and petrochemical industries. The discharge of ammonia-containing wastewater into natural water bodies can cause eutrophication, odor generation, and toxicity to aquatic life, making its removal a vital environmental concern. Over the past decades, a variety of treatment technologies—including biological nitrification–denitrification, ion exchange, membrane separation, and air stripping—have been developed to reduce ammonia concentrations in industrial wastewater [1–3].

However, the selection of an effective and economically feasible process largely depends on the composition of the wastewater and operational constraints. Among the available options, air stripping and Wet Air Oxidation (WAO) have been identified as two promising techniques for ammonia removal under different conditions. Air stripping relies on the mass transfer of ammonia gas from the liquid phase to the air phase, which is enhanced by increasing temperature and pH. In contrast, the WAO process uses elevated temperatures (200–320 °C) and pressures (5–15 bar) to oxidize organic and nitrogenous compounds in the presence of compressed air, converting ammonia into nitrogen gas and water.

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Although both methods have been extensively studied, few comparative simulations exist that evaluate their performance under identical operational conditions. Furthermore, most previous studies have focused either on experimental setups or on limited operational parameters without integrating thermodynamic modeling. The present study aims to fill this gap by developing detailed Aspen Plus simulations for both air stripping and WAO processes using the ENRTL-RK thermodynamic model, which accurately represents non-ideal electrolyte behavior.
The main objectives of this work are:

- To model and simulate both ammonia removal processes using consistent input conditions.
- To compare their energy requirements, operating parameters, and ammonia recovery efficiency.
- To identify the most technically and environmentally efficient method for industrial-scale application.

The results of this study are expected to support process selection and optimization in wastewater treatment facilities, especially in chemical and petrochemical industries dealing with high-ammonia effluents.

3. MATERIALS AND METHODS

This study employs a simulation-based approach to compare the performance of air stripping and wet air oxidation (WAO) for the removal of ammonia from industrial wastewater. Both processes were modeled using Aspen Plus v14, which enables thermodynamic and kinetic simulations of chemical processes.

3.1. Process description

In the air stripping process, the wastewater stream containing dissolved ammonia is first preheated to improve ammonia volatility. Air is injected counter-currently through a packed tower, facilitating the transfer of ammonia gas into the air stream. A caustic solution (NaOH) is also introduced to raise the pH above 10.5, ensuring that ammonia remains in its gaseous form (NH_3). The overall design of the air stripping column and associated units was developed in Aspen Plus using standard unit operation blocks such as RadFrac for mass-transfer modeling.
The process flow diagram for air stripping is illustrated in Figure 1.

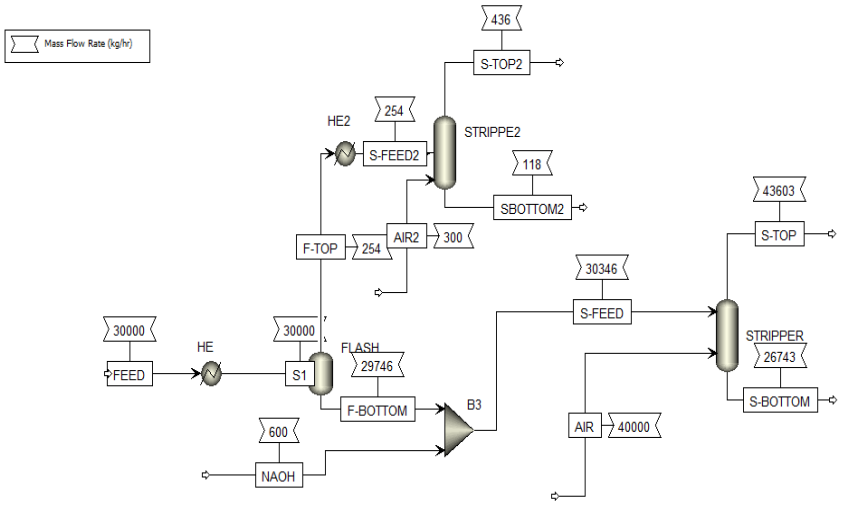

Figure 1. Process flow diagram of the air stripping system.

In the WAO process, the pretreated effluent is mixed with compressed air and fed into a reactor operating at high temperature (200–320 °C) and pressure (5–15 bar). The oxidation reactions are simulated using stoichiometric and equilibrium assumptions, converting ammonia to nitrogen gas and water. The process flow diagram of the WAO system is shown in Figure 2.

3.2. Simulation conditions and parameters

Both air stripping and wet air oxidation (WAO) processes were simulated under comparable feed and operating conditions to ensure consistency. The wastewater feed rate was 30,000 kg/h at an inlet temperature of 20 °C and pressure of 1 bar, preheated to 90 °C before entering each system. The air flow rate was set to 40,000 kg/h for the stripping column and 35,000 kg/h for the WAO reactor. Sodium hydroxide was added at rates of 600 kg/h and 520 kg/h, respectively, to adjust the alkalinity during pretreatment. The operating pressures were 1 bar for air stripping and 10 bar for WAO, with corresponding operating temperatures of 90 °C and 320 °C. All thermophysical and phase-equilibrium properties were calculated using the ENRTL-RK model to account for non-ideal electrolyte behavior.

4. RESULTS AND DISCUSSION

The simulation results provided valuable insights into the thermodynamic and operational behavior of both ammonia removal processes. The comparison between air stripping and wet air oxidation (WAO) reveals distinct mechanisms and efficiencies that determine their suitability for different industrial applications.

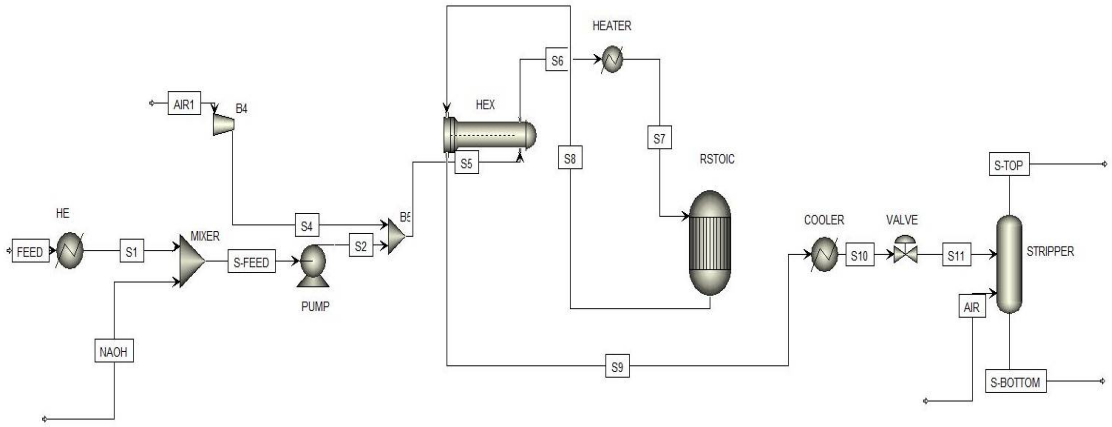

Figure 2. Process flow diagram of the wet air oxidation system

4.1. Air stripping performance

The air stripping process demonstrated a removal efficiency of approximately 92.9%, indicating its effectiveness for low-to-moderate ammonia concentrations in wastewater. Increasing both the temperature and air-to-liquid ratio was found to enhance ammonia transfer from the aqueous to the gas phase, consistent with Henry's law. However, beyond an optimal temperature of 90 °C, further heating provided negligible improvement due to equilibrium limitations.

Raising the pH using NaOH significantly shifted the equilibrium toward gaseous ammonia, confirming that alkalinity control plays a crucial role in the stripping efficiency. The process is simple and energy-efficient but requires careful handling of the ammonia-rich off-gas, which must be further treated or recovered.

4.2. Wet air oxidation (WAO) performance

The WAO process, modeled under a reactor temperature of 320 °C and pressure of 10 bar, achieved a higher ammonia conversion of 98.53%. The oxidation reactions were simulated as equilibrium-based transformations converting ammonia and other organics into nitrogen gas, CO_2, and water. As expected, elevated pressure promoted oxygen solubility in the liquid phase, enhancing the oxidation rate.

The WAO process, however, requires significantly higher energy input for heating and compression compared with air stripping. Therefore, its implementation is more suitable for effluents with high organic and ammonia loads, where simultaneous oxidation of other contaminants can justify the higher operational cost.

4.3. Comparative Evaluation

While air stripping offers lower energy consumption and simpler operation, WAO provides nearly complete ammonia removal and superior treatment for complex wastewater. Thus, the optimal selection depends on wastewater composition and the availability of energy resources.

The modeling results are consistent with literature findings [4–5], confirming the reliability of the ENRTL-RK thermodynamic model for electrolyte systems and validating the accuracy of the simulated performance under industrially realistic conditions.

5. CONCLUSION

The simulation results indicated that both air stripping and wet air oxidation (WAO) are effective methods for ammonia removal from industrial wastewater. While air stripping achieved 92.9% efficiency with lower energy demand, WAO reached 98.53% efficiency under high temperature and pressure, ensuring nearly complete ammonia oxidation. Overall, WAO offers superior performance but at higher energy cost; therefore, future research should explore hybrid or optimized systems to enhance ammonia removal efficiency while minimizing energy consumption.

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