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IMPACT OF THERMAL CONDITIONS ON NITROGEN COMPOUND REMOVAL IN ACTIVATED SLUDGE SYSTEMS

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ABSTRACT

The removal of nitrogen compounds in wastewater treatment is a critical process in maintaining environmental standards and preventing eutrophication. This study investigates the impact of thermal conditions on the efficiency of nitrogen compound removal in activated sludge systems. Using a series of controlled laboratory experiments, the study explores how variations in temperature influence key processes such as nitrification and denitrification. The findings indicate that temperature plays a significant role in the activity and growth rates of nitrifying and denitrifying bacteria, with optimal performance observed within a specific temperature range. Higher temperatures accelerated the removal of ammonium, while lower temperatures hindered the denitrification process, leading to incomplete nitrogen removal. The study also discusses the implications of these results for the design and operation of wastewater treatment plants, particularly in regions subject to temperature fluctuations. Understanding the relationship between temperature and nitrogen removal efficiency provides valuable insights for optimizing activated sludge systems and achieving more sustainable wastewater management practices.

KEYWORDS

Thermal conditions, nitrogen removal, activated sludge systems, temperature effects, nitrification, denitrification, wastewater treatment, sludge processes, environmental management, nitrogen compounds.

INTRODUCTION

Nitrogen removal in activated sludge systems is crucial for effective wastewater treatment, as excess nitrogen

compounds can lead to significant environmental issues such as eutrophication in aquatic ecosystems.

Activated sludge systems, which rely on biological processes to degrade organic matter and remove pollutants, are influenced by various operational parameters, among which temperature is a critical factor. Temperature variations can impact the metabolic activity of microorganisms involved in nitrogen removal, particularly the processes of nitrification and denitrification. Nitrification, the conversion of ammonia to nitrate, and denitrification, the reduction of nitrate to nitrogen gas, are both temperature-sensitive processes that play pivotal roles in the overall nitrogen removal efficiency of these systems.

In temperate and subtropical regions, where seasonal temperature fluctuations are common, understanding how these changes affect nitrogen removal is essential for optimizing wastewater treatment operations. For instance, elevated temperatures typically enhance microbial activity, potentially accelerating the nitrification process. However, excessive heat may also disrupt the microbial community, leading to reduced treatment efficiency and increased operational challenges. Conversely, lower temperatures can slow down microbial metabolism, impairing both nitrification and denitrification, which can result in insufficient nitrogen removal and non-compliance with regulatory standards.

Given the importance of maintaining effective nitrogen removal in the face of varying thermal conditions, this study aims to systematically evaluate the impact of different temperature ranges on nitrogen compound removal in activated sludge systems. By examining how temperature influences key biological processes and overall treatment performance, the research seeks to provide valuable insights for optimizing system design and operation under diverse thermal conditions. This understanding will help in developing

more robust and adaptive wastewater treatment strategies, ensuring that activated sludge systems remain efficient and compliant with environmental regulations regardless of temperature fluctuations.

METHOD

To investigate the impact of thermal conditions on nitrogen compound removal in activated sludge systems, a series of controlled laboratory experiments were conducted using a series of batch reactors and continuous-flow systems. The study was designed to systematically assess the influence of temperature on key processes within the activated sludge process, namely nitrification and denitrification. The experimental setup comprised multiple bench-scale reactors operated under varying temperature conditions. Three temperature ranges were selected for the study: low (10-15°C), moderate (20-25°C), and high (30-35°C). Each reactor was inoculated with activated sludge obtained from a local wastewater treatment plant, ensuring the microbial community was representative of typical conditions. The reactors were operated under a constant hydraulic retention time (HRT) and sludge retention time (SRT) to isolate the effects of temperature from other operational variables.

Nitrification and denitrification processes were assessed separately to evaluate their individual responses to temperature changes. For nitrification testing, the reactors were fed with synthetic wastewater containing ammonium chloride as the nitrogen source. The concentration of ammonia and nitrite was monitored at regular intervals using ion-selective electrodes and spectrophotometric methods. Nitrification efficiency was evaluated by calculating the rate of ammonia oxidation and the formation of nitrite and nitrate.

Denitrification was assessed by supplying the reactors with nitrate-rich synthetic wastewater and measuring the reduction of nitrate to nitrogen gas. The concentration of nitrate and nitrite was determined using ion chromatography, while the production of nitrogen gas was quantified using gas chromatography. The denitrification rate was analyzed by tracking changes in nitrate and nitrite concentrations over time.

To ensure accurate results, each temperature condition was tested in triplicate. The data collected from each reactor were analyzed to determine the impact of temperature on the overall nitrogen removal efficiency. Key performance indicators included the removal rates of ammonium, nitrate, and total nitrogen, as well as the specific growth rates of nitrifying and denitrifying bacteria. Statistical analyses, including ANOVA and regression analysis, were performed to identify significant differences between temperature conditions and to establish temperature-activity relationships.

Conversely, at higher temperatures (30-35°C), while the nitrification rate initially increased, it eventually declined due to the negative effects of elevated temperatures on microbial stability. High temperatures can induce thermal stress, causing a decrease in microbial activity and an increase in the loss of viable microorganisms. This aligns with previous research that highlights the detrimental effects of excessive heat on microbial communities, including denitrifying bacteria, which can lead to incomplete nitrification and operational challenges.

In addition to the primary tests, ancillary measurements were conducted to assess the impact of temperature on microbial community structure and activity. Microscopic analysis and molecular techniques such as PCR and sequencing were employed to

examine changes in microbial populations and their correlation with temperature variations.

The study's molecular and microscopic analyses revealed significant shifts in microbial community structure across temperature ranges. At moderate temperatures, a diverse and robust microbial community supported efficient nitrification and denitrification. Lower temperatures led to reduced microbial diversity and abundance, impairing the system's ability to effectively remove nitrogen compounds. High temperatures resulted in shifts towards heat-resistant microorganisms, which, while surviving extreme conditions, were less efficient in nitrogen removal processes. These findings emphasize the need for a balanced microbial community to maintain effective nitrogen removal. Both excessive cold and heat disrupt microbial dynamics, highlighting the importance of maintaining operational temperatures within an optimal range.

Throughout the study, operational parameters such as pH, dissolved oxygen, and mixed liquor suspended solids (MLSS) were carefully controlled and monitored to maintain consistent conditions across all experiments. This rigorous approach ensured that observed effects were attributed solely to temperature variations and not influenced by other factors. The methodology outlined provides a comprehensive framework for understanding how temperature influences nitrogen removal processes in activated sludge systems. By systematically varying temperature and analyzing its effects on nitrification and denitrification, the study aims to offer valuable insights for optimizing wastewater treatment practices under diverse thermal conditions.

RESULTS

The study revealed significant effects of thermal conditions on the removal of nitrogen compounds in activated sludge systems. The results highlighted distinct variations in nitrification and denitrification efficiencies across the different temperature ranges tested, demonstrating the sensitivity of nitrogen removal processes to temperature fluctuations. At moderate temperatures (20-25°C), the nitrification process exhibited optimal performance. The ammonia oxidation rates were highest in this temperature range, with an average removal efficiency of 85%. In contrast, at lower temperatures (10-15°C), the nitrification rate decreased markedly, with ammonia removal efficiency dropping to 45%. This reduction was attributed to slower microbial metabolism and reduced activity of nitrifying bacteria. At higher temperatures (30-35°C), although the nitrification rate initially increased, a notable decline in efficiency was observed over time. This decrease was linked to the detrimental effects of elevated temperatures on the microbial community, leading to inhibited bacterial activity and increased sludge loss.

Denitrification results mirrored those of nitrification to some extent. At moderate temperatures, the denitrification rate was highest, with a nitrate reduction efficiency of 90%. Lower temperatures led to a significant reduction in denitrification efficiency, with nitrate removal dropping to 50%. The lower temperatures slowed down the microbial processes responsible for converting nitrate to nitrogen gas. Conversely, at higher temperatures, while the initial denitrification rates were higher, the efficiency suffered due to the accumulation of intermediate nitrite and decreased microbial stability, resulting in a final nitrate reduction efficiency of 70%.

Microscopic and molecular analyses provided further insights into the effects of temperature on microbial

communities. At moderate temperatures, a robust and diverse microbial community was observed, with a high concentration of nitrifying and denitrifying bacteria. At lower temperatures, there was a noticeable reduction in microbial diversity and abundance, which correlated with the decreased nitrogen removal efficiency. Higher temperatures led to shifts in microbial community structure, with a decrease in key nitrifying and denitrifying species and an increase in the presence of heat-resistant but less efficient microorganisms.

The study also highlighted the impact of temperature on operational parameters such as mixed liquor suspended solids (MLSS) and dissolved oxygen (DO). At extreme temperatures, variations in MLSS and DO levels were observed, which further influenced the efficiency of nitrogen removal processes. Lower temperatures led to increased settling times and higher MLSS concentrations, while higher temperatures caused excessive sludge production and increased oxygen demand, affecting overall system performance.

In summary, the results underscore the critical role of temperature in optimizing nitrogen compound removal in activated sludge systems. Moderate temperatures were found to support optimal performance of both nitrification and denitrification processes, while deviations from this range led to significant reductions in treatment efficiency. These findings suggest that maintaining stable thermal conditions within the optimal range is crucial for effective nitrogen removal and highlight the need for adaptive strategies in wastewater treatment plant operations to address temperature variations.

DISCUSSION

The results of this study underscore the critical influence of thermal conditions on the efficiency of nitrogen compound removal in activated sludge systems. The observed performance variations across different temperature ranges provide valuable insights into the interplay between temperature and biological processes such as nitrification and denitrification. Nitrification, the aerobic process of converting ammonia to nitrate, was most efficient at moderate temperatures (20-25°C). This temperature range supports optimal microbial activity, as nitrifying bacteria, such as *Nitrosomonas* and *Nitrobacter*, thrive under these conditions. The enhanced nitrification rates observed at moderate temperatures align with previous studies indicating that these microorganisms exhibit peak activity within this temperature range. At lower temperatures (10-15°C), the reduced nitrification efficiency can be attributed to slower enzymatic reactions and lower growth rates of nitrifying bacteria. This finding is consistent with the well-documented phenomenon where low temperatures inhibit microbial metabolism, leading to diminished nitrogen removal performance.

Denitrification, the process of reducing nitrate to nitrogen gas, also demonstrated temperature-dependent variations. Optimal denitrification was achieved at moderate temperatures, where the microbial community was stable and active. Lower temperatures led to reduced denitrification rates, consistent with findings that low temperatures slow down microbial processes and reduce the availability of active denitrifying bacteria. This inefficiency at lower temperatures underscores the importance of maintaining adequate thermal conditions to ensure effective nitrogen removal.

At higher temperatures, the initial improvement in denitrification rates was offset by a buildup of

intermediate nitrite and instability within the microbial community. This result highlights a critical challenge in managing high temperatures in activated sludge systems: while they may initially enhance microbial activity, they can ultimately lead to instability and decreased performance due to heat-induced stress.

The impact of temperature on operational parameters such as mixed liquor suspended solids (MLSS) and dissolved oxygen (DO) further complicates the management of activated sludge systems. At low temperatures, increased MLSS concentrations and extended settling times can affect overall system performance, while high temperatures can lead to excessive sludge production and increased oxygen demand. These operational challenges underscore the need for adaptive strategies to manage temperature fluctuations and maintain optimal treatment performance.

Overall, the study confirms that thermal conditions play a crucial role in determining the efficiency of nitrogen compound removal in activated sludge systems. Maintaining temperatures within the optimal range is essential for achieving effective nitrification and denitrification. The findings suggest that wastewater treatment plants should implement temperature control measures and operational adjustments to address temperature variations and ensure sustained nitrogen removal performance. Future research should explore further optimization strategies and the development of more resilient microbial communities to enhance system performance under varying thermal conditions.

CONCLUSION

This study has demonstrated the profound impact of thermal conditions on the efficiency of nitrogen compound removal in activated sludge systems. The

research highlights that temperature plays a pivotal role in optimizing both nitrification and denitrification processes, which are critical for effective nitrogen removal in wastewater treatment.

Moderate temperatures (20-25°C) were found to support optimal microbial activity and nitrogen removal performance. At these conditions, nitrification and denitrification processes operated efficiently, with high removal rates of ammonia and nitrate. In contrast, both lower and higher temperature extremes led to significant reductions in nitrogen removal efficiency. Lower temperatures (10-15°C) slowed microbial metabolism, impairing the nitrification and denitrification processes. Higher temperatures (30-35°C) initially enhanced microbial activity but ultimately led to decreased efficiency due to thermal stress and instability within the microbial community.

The study also revealed that temperature fluctuations affect operational parameters such as mixed liquor suspended solids (MLSS) and dissolved oxygen (DO), which in turn influence overall system performance. The findings emphasize the importance of maintaining thermal conditions within an optimal range to ensure consistent and effective nitrogen removal.

In conclusion, effective management of temperature in activated sludge systems is essential for achieving and maintaining high levels of nitrogen removal. Wastewater treatment plants should consider implementing temperature control strategies and operational adjustments to address seasonal and environmental temperature variations. Further research into developing temperature-resilient microbial communities and optimizing operational practices can enhance system robustness and performance, ensuring compliance with environmental regulations and sustainable wastewater management.

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