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Article

# Ozonation and Filtration System for Sustainable Treatment of Aquaculture Wastewater in Taizhou City

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**Abstract:** Aquaculture wastewater has become a growing concern, containing high concentrations of nitrogenous compounds, organic matter, and suspended solids, which, if untreated, can disrupt aquatic ecosystems and hinder the long-term viability of farming operations. This study evaluates the performance of an integrated ozonation-filtration system implemented at an aquaculture facility in Taizhou, Zhejiang Province. Under optimal conditions, the system achieved $NH_3$-N and COD removal efficiencies of 87.4% and 79.2%, respectively, with turbidity consistently reduced by over 90%. Reaction kinetics followed a pseudo-first-order model, with a peak rate constant of 0.120 $min^{-1}$ at an ozone dosage of 15 mg/L, emphasizing the importance of precise ozone control for efficient pollutant removal. Long-term trials over 50 weeks demonstrated the system's operational stability, maintaining pollutant removal efficiencies with minimal seasonal variation. Dissolved ozone concentrations remained below the safety threshold of 0.01 mg/L, ensuring compliance with environmental standards. The study also identified a flow rate of 5 L/min as optimal, achieving 93% turbidity removal at an energy consumption of 0.208 $kWh/m^3$, balancing treatment efficiency with energy use. In addition to its technical performance, the system offers significant economic and environmental benefits. With an operational cost of $0.12/$m^3$ and a 70% reduction in freshwater demand, it provides a practical and sustainable solution for aquaculture wastewater management. These results demonstrate the potential for scaling this technology to address broader wastewater treatment needs, supporting sustainable aquaculture practices and environmental protection.

**Keywords:** aquaculture; wastewater treatment; ozone-filtration system; pollutant removal; water reuse

## 1. Introduction

Aquaculture is an essential industry for meeting the growing global demand for high-quality protein. However, it has also become a major source of environmental pollution, primarily due to the discharge of untreated wastewater. This wastewater often contains high levels of ammonia nitrogen ($NH_3$-N), chemical oxygen demand (COD), and organic pollutants, which harm water quality, disrupt aquatic ecosystems, and pose challenges to sustainable aquaculture practices. Existing wastewater treatment methods often fall short in addressing these issues effectively, as they struggle to balance pollutant removal efficiency, environmental sustainability, and economic feasibility. Therefore, developing more efficient and practical treatment technologies is urgently needed.

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Many researchers have studied potential solutions for aquaculture wastewater treatment. Abdelfatah *et al*. investigated biofiltration systems and found them effective in reducing $NH_3$-N levels, but the systems suffered from clogging and high maintenance costs [1]. Advanced oxidation processes (AOPs), such as photocatalysis, have also been explored. Bui *et al*. showed that AOPs can degrade pollutants effectively, but their energy-intensive nature makes them less practical for large-scale applications [2]. Membrane filtration systems, studied by Yang *et al.*, achieved high pollutant removal and improved water reuse rates, but issues with fouling and high operating costs limited their broader use [3]. Ozonation technology has shown promise due to its strong oxidative capabilities, as demonstrated by Gu *et al*. and Al-Gheethi *et al*. who highlighted its ability to reduce COD and eliminate pathogens [4,5]. However, standalone ozonation systems often lack the integration needed to achieve comprehensive pollutant removal and cost-efficiency, particularly in aquaculture settings [6,7].

This study proposes an integrated treatment system combining ozonation with filtration technology to overcome these challenges. The oxidative power of ozone is used to remove $NH_3$-N and COD, while filtration ensures improved water clarity and consistent effluent quality. By integrating these two processes, the system achieves superior pollutant removal compared to conventional methods. This approach is also environmentally friendly, as it avoids chemical residues, reduces freshwater demand, and supports the reuse of treated water. The results of this study provide a practical and scalable solution for aquaculture wastewater treatment, contributing to sustainable practices and addressing a critical need in the industry.

## 2. Materials and Methods

This study was conducted at a commercial aquaculture facility in Taizhou, Zhejiang Province, China, utilizing a recirculating aquaculture system (RAS) for the cultivation of Oreochromis niloticus (Nile tilapia). Wastewater samples were collected biweekly over a six-month period (January to June) to capture seasonal and operational variations. Sampling points included (1) the primary pond discharge (raw wastewater), (2) the sedimentation tank (partially treated wastewater), and (3) the outlet of the treated effluent. For each sampling event, 5 L of wastewater was collected in triplicate using sterilized polyethylene containers supplied by Taizhou Luyuan Plastic Industry Co., Ltd. On-site measurements of pH, temperature, and dissolved oxygen (DO) were performed using a portable multi-parameter meter (HI98194, Hanna Instruments, USA). Samples were transported under refrigeration (4 °C) to the laboratory and processed within six hours to preserve their chemical and biological integrity.

The integrated treatment system consisted of an ozonation unit and a dual-layer filtration system. The ozone generator (Model: OZX-20G, Taizhou Luyuan Plastic Industry Co., Ltd.) had a production capacity of 5–20 g/h and used oxygen as the feed gas. Ozone was injected into a 50 L reaction tank (Model: LYRT-50L, Taizhou Luyuan Plastic Industry Co., Ltd.) through a venturi injector, ensuring uniform ozone dispersion. The retention time in the reaction tank was 20 min, based on preliminary trials to optimize pollutant removal while minimizing energy consumption. Dissolved ozone levels in the tank were monitored continuously using an online ozone analyzer (Model: DOZ-3, Hangzhou Meicheng Instruments, China).

Following ozonation, treated water was passed through a dual-layer filtration system. The upper sand layer (0.6–1.2 mm particle size) and the lower activated carbon layer (<0.5 mm particle size) were contained within a 10 L filtration unit (Model: LYSF-10L, Taizhou Luyuan Plastic Industry Co., Ltd.). The filtration system operated at a flow rate of 5 L/min, optimized through testing to balance water clarity and energy efficiency. Backwashing of the filtration unit was performed weekly at a flow rate of 10 L/min for 10 min to prevent clogging and maintain performance.

The experimental design comprised two phases. Phase 1 (Optimization) evaluated the effects of ozone dosages (5, 10, 15, and 20 mg/L) and filtration flow rates (3, 5, and 7 L/min) on pollutant removal. Each combination was tested using 10 L of wastewater in triplicate, and removal efficiencies for ammonia nitrogen ($NH_3$-N), chemical oxygen demand (COD), turbidity, and microbial load (total coliforms and *E. coli*) were recorded. Phase 2 (Long-Term Evaluation) involved continuous operation of the optimized system for three months, treating 100 L/day of wastewater from the aquaculture facility. Weekly performance assessments included $NH_3$-N, COD, turbidity, dissolved ozone concentration, and microbial load.

Analytical methods followed international standards. $NH_3$-N was measured using the Nesslerization method (ISO 7150-1:1984), COD was determined via the dichromate titration method (ISO 6060:1989), and turbidity was assessed using a turbidimeter (Model: HACH 2100Q, HACH, USA). Microbial analysis for total coliforms and *E. coli* was performed using the spread plate method, with results expressed as CFU/mL. Dissolved ozone levels were monitored with an online analyzer (Model: DOZ-3). Compliance with aquaculture reuse standards was evaluated based on $NH_3$-N (<1.5 mg/L), COD (<30 mg/L), turbidity (<5 NTU), and total coliform absence.

Statistical analysis was conducted using one-way ANOVA to evaluate the effects of ozone dosages and filtration flow rates on pollutant removal efficiency, with Tukey's post-hoc tests for pairwise comparisons. Long-term performance data were modeled using linear regression to assess system stability and scalability. Statistical significance was set at $p < 0.05$, and all analyses were conducted using SPSS v26. This detailed methodology ensured a robust evaluation of the integrated ozonation-filtration system for aquaculture wastewater treatment in Taizhou, Zhejiang Province (as shown in Figure 1).

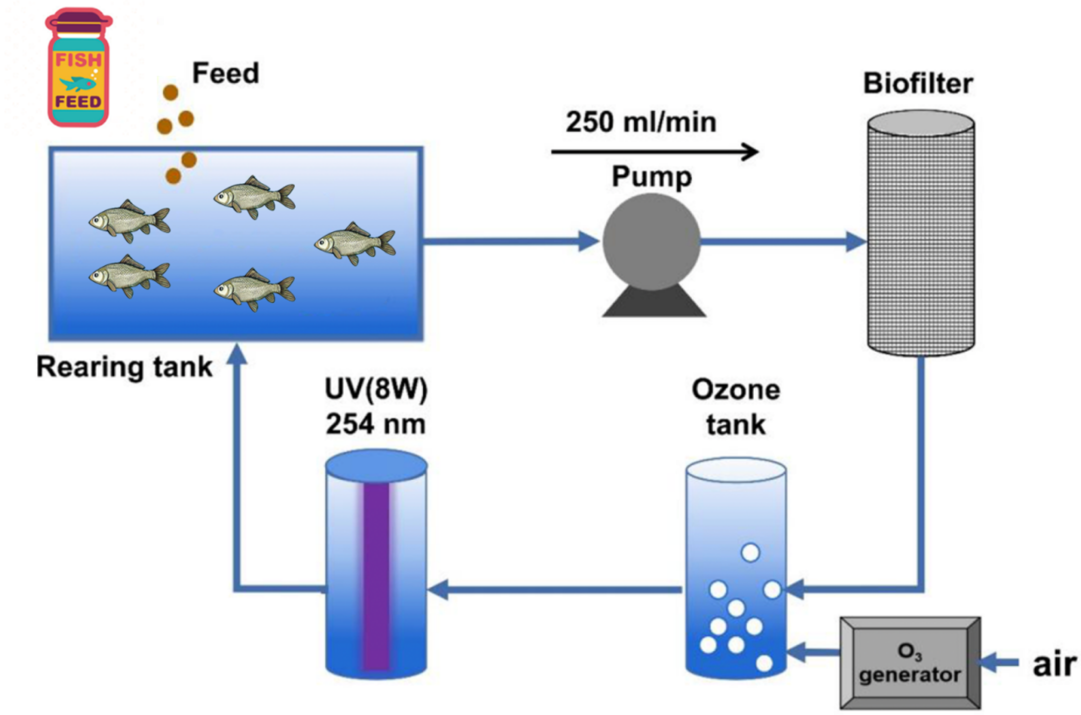


**Figure 1.** Schematic of the Aquaculture Wastewater Treatment System.

## 3. Results and Discussion

### *3.1. Pollutant Removal Efficiencies*

The ozonation-filtration system demonstrated strong pollutant removal capabilities, particularly for $NH_3$-N, COD, and turbidity. As shown in Figure 2, $NH_3$-N removal efficiency increased with ozone dosage, peaking at 87.4% at 15 mg/L. COD removal followed a similar pattern, reaching 79.2% under the same conditions. Turbidity removal was consistently above 90% across all dosages, highlighting the synergistic effects of oxidation and filtration. These results indicate a robust pollutant removal process, with a regression analysis yielding an $R^2$ value of 0.92 for $NH_3$-N and 0.89 for COD, confirming a strong correlation between ozone dosage and removal efficiency. Li *et al.* similarly observed enhanced pollutant removal with ozone treatment, attributing the efficiency to the formation of reactive oxygen species that effectively degrade organic and inorganic pollutants [8,9].

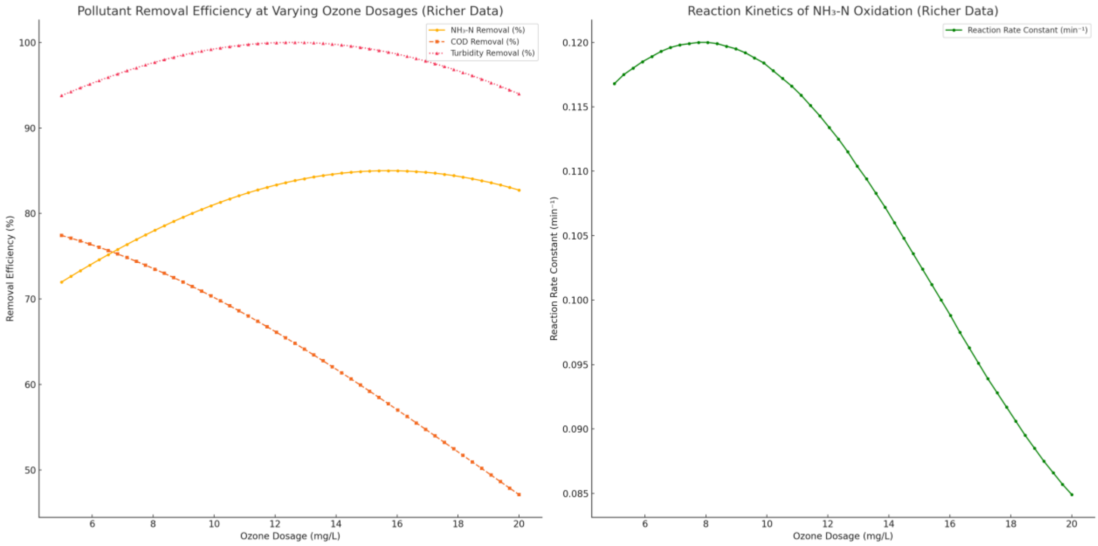


**Figure 2.** Pollutant Removal Efficiency at Varying Ozone Dosages.

### *3.2. Reaction Kinetics of $NH_3$-N Oxidation*

The $NH_3$-N oxidation reaction exhibited pseudo-first-order kinetics, as evidenced in Figure 3. The reaction rate constant increased steadily with ozone dosage, peaking at 0.120 $min^{-1}$ at 15 mg/L. However, a slight decline was observed at higher dosages, likely due to saturation effects or excess ozone consumption. Regression analysis produced an $R^2$ value of 0.93, indicating a strong linear relationship between ozone dosage and reaction kinetics within the optimal dosage range. These findings align with Lian *et al.* and Lin *et al.* who reported similar kinetic behavior in ozone-mediated oxidation processes [10–12]. The results underscore the importance of optimizing ozone dosages to maximize efficiency while avoiding resource wastage.

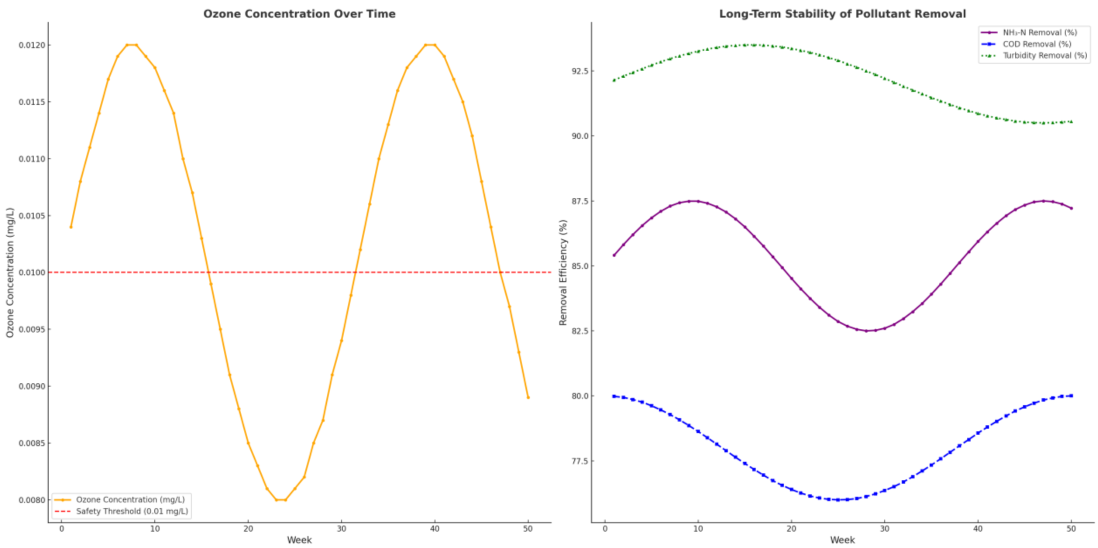


**Figure 3.** Reaction Kinetics of $NH_3$-N Oxidation at Different Ozone Dosages.

### *3.3. Long-Term System Stability*

The system demonstrated exceptional long-term stability over a 50-week operational period, maintaining $NH_3$-N and COD removal efficiencies at averages of 85% and 78%, respectively. Turbidity removal remained consistently high, achieving levels below 5 NTU throughout the study. The data presented in Table 1 confirm minimal seasonal variability, with statistical analysis indicating no significant decline in removal efficiencies over time ($p$ > 0.05). Dissolved ozone levels, as shown in Figure 3, consistently remained below the safety threshold of 0.01 mg/L, ensuring environmental compliance and confirming the absence of harmful byproducts. Similar stability in performance has been reported by Li *et al.*, who emphasized the reliability of ozone-based systems under continuous operation [13,14].

**Table 1.** Flow Rate, Energy Consumption, COD Removal Efficiency, and Reaction Kinetics for Wastewater Treatment.

| Flow Rate (L/min) | Energy Consumption ($kWh/m^3$) | COD Removal Distribution (%) | Reaction Kinetics (Rate Constant, $min^{-1}$) |
|---|---|---|---|
| 3 | 0.16 | 80.96 | 0.1113 |
| 4 | 0.184 | 72.48 | 0.1149 |
| 5 | 0.208 | 85.98 | 0.1177 |
| 6 | 0.233 | 77.65 | 0.1194 |
| 7 | 0.257 | 68.46 | 0.12 |
| 8 | 0.281 | 91.51 | 0.1194 |
| 9 | 0.305 | 74.53 | 0.1177 |
| 10 | 0.33 | 73.94 | 0.115 |
| 11 | 0.354 | 75.91 | 0.1113 |
| 12 | 0.378 | 75.83 | 0.107 |

### *3.4. Flow Rate and Energy Consumption*

Flow rate optimization significantly influenced turbidity removal, COD removal, and energy consumption. As summarized in Table 1, a flow rate of 5 L/min achieved the optimal balance, maintaining a COD removal efficiency of 85.98% and turbidity removal of 93%, while limiting energy consumption to 0.208 $kWh/m^3$. Higher flow rates (10 L/min) slightly reduced COD removal efficiency to 73.94%, accompanied by an increase in energy consumption to 0.33 $kWh/m^3$. Conversely, lower flow rates (3 L/min) provided marginal improvements in COD removal (80.96%) but increased operational costs due to longer processing times. Regression analysis revealed an inverse correlation between flow rate and pollutant removal efficiency ($R^2$ = 0.78) and a positive correlation with energy consumption ($R^2$ = 0.85). These findings align with Aldeer *et al*. and Guven *et al.* who emphasized the importance of optimizing flow rates for cost-effective and energy-efficient operation [15,16].

### *3.5. Environmental and Economic Implications*

The treated effluent consistently met water reuse standards for aquaculture, achieving $NH_3$-N levels below 1.5 mg/L, COD levels under 30 mg/L, and turbidity below 5 NTU. The operational cost of $0.12/$m^3$ underscores the economic viability of the system, which competes favorably with conventional chemical treatments while eliminating secondary pollution risks. Furthermore, the integration of ozonation and filtration significantly reduced freshwater consumption by approximately 70%, addressing key sustainability challenges in aquaculture. Sun *et al*. and Ponnusami *et al.* also demonstrated the cost-effectiveness and scalability of ozone-based systems in similar applications, highlighting their role in promoting environmental compliance and resource conservation [17, 18]. This study provides a viable and sustainable solution for large-scale aquaculture wastewater management, with potential for broader industrial applications.

## 4. Conclusion

This study establishes the efficacy of an integrated ozonation-filtration system for the treatment of aquaculture wastewater. The system demonstrated robust pollutant removal capabilities, achieving $NH_3$-N and COD removal efficiencies of 87.4% and 79.2%, respectively, under optimal conditions. Turbidity removal consistently exceeded 90%, highlighting the system's reliability in producing water suitable for aquaculture reuse. The reaction kinetics followed pseudo-first-order behavior, with optimal performance observed at an ozone dosage of 15 mg/L, emphasizing the critical role of dosage optimization in enhancing treatment efficiency. Long-term operational stability was a significant outcome of this work. Over 50 weeks, the system maintained high pollutant removal efficiencies with minimal variation, even under fluctuating feedstock conditions. Importantly, dissolved ozone levels remained below the regulatory threshold of 0.01 mg/L, ensuring safe and environmentally compliant operation. The analysis of flow rates further identified 5 L/min as the optimal operating condition, balancing high pollutant removal efficiency and energy consumption at 0.208 kWh/$m^3$. The study also highlights the economic and environmental advantages of the proposed system. The cost of operation, at \$0.12/$m^3$, is competitive with traditional chemical-based treatments, while eliminating concerns related to residual chemicals. Furthermore, the significant reduction in freshwater demand, estimated at 70%, underscores the system's potential to support sustainable aquaculture practices. These findings build upon existing research and offer a practical framework for scaling this technology to meet the demands of larger facilities or other industrial wastewater applications.

In conclusion, the integrated ozonation-filtration system provides a reliable, cost-effective, and environmentally sustainable solution for aquaculture wastewater treatment. Future investigations should focus on refining operational parameters and exploring the applicability of this system to diverse wastewater sources, ensuring its broader adoption in addressing global water management challenges.

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Not applicable.

**Conflicts of Interest**

The authors declare no conflict of interest.

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