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Exploration on the Treatment of Aquaculture Wastewater Using Biological Filter Technology

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Abstract

The wastewater discharged from aquaculture industry continues to grow in China. Studies on ecological treatment technologies for solving aquaculture wastewater are urgent. This paper analyzes the water quality characteristics of recirculating aquaculture systems and constructs a three-stage aerated biological filter comprising "fiber filter media+ceramic particles+zeolite". This study investigated the treatment effect of this process on wastewater from recirculating aquaculture systems, providing technical support for the application and promotion of recirculating aquaculture treatment systems.

Keywords

Biological Filter; Aquaculture Wastewater; Recirculating Aquaculture System; Nitrogen Utilization Efficiency.

1. Introduction

In recent years, aquaculture has expanded in scale and intensified in production, leading to increasingly prominent issues of aquaculture wastewater and ecological damage. Amid growing market demand, measures to increase aquaculture density have been implemented to boost production. However, the pace of timely and efficient wastewater treatment has failed to keep up, resulting in severe damage to China's aquatic ecosystems. The traditional "large-scale intake and discharge" model not only wastes vast amounts of water resources but also discharges aquaculture wastewater containing substantial suspended solids and pollutants, leading to eutrophication in surrounding water bodies [1].The goal of aquaculture wastewater treatment no longer stops at water purification but increasingly pursues recycling and reuse [2].This approach not only facilitates intensive production but also reduces environmental pollution, aligning with the principles of sustainable development. Thus, it emerged as a major direction for contemporary aquaculture. In terms of water quality, recirculating aquaculture systems exhibit characteristics such as high nitrogen and phosphorus levels, substantial organic matter content, significant suspended solids with small particle sizes, and favorable biochemical properties,which makes it difficult for a single biochemical degradation method to achieve satisfactory treatment results. Therefore, relatively speaking, physical and biological interception methods are more commonly employed to reduce pollutants in subsequent processes, followed by advanced biochemical reactions to achieve highly efficient removal. Biological filter as the core process component in recirculating aquaculture systems utilizes microbial biofilms attached to filter media to eliminate pollutants from aquaculture water. Optimizing multi-stage filtration processes has emerged as a key technology for treating aquaculture wastewater [3].Some researches have found that the performance of biological filters utilizing natural filter media can provide a low-cost solution for treating aquaculture wastewater [4]. Addressing nitrogen and phosphorus pollution in aquaculture wastewater, the construction of a multi-stage aerated biological filtration system and the study on the effects of hydraulic retention time (HRT) on ammonia nitrogen and total nitrogen removal efficiencies

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have become a research focus [5]. In wastewater treatment processes, balancing the conflict between removal efficiency and minimizing equipment footprint remains a pressing challenge in the advancement of wastewater treatment technologies. This paper presents a combined biological filter process specifically designed for recirculating aquaculture systems, investigating its treatment performance. These data hold significant implications for aquaculture wastewater treatment and the development of the fisheries industry.

2. Research Methods

The aerated biological filter is an innovative wastewater treatment process that integrates contact oxidation with conventional filtration. It enables solid-liquid-biochemical reactions within a single reactor, combining both biochemical treatment and filtration functions. This technology has garnered significant attention in contemporary wastewater management. The hierarchical arrangement of biological filters and the selection of biological fillers directly impact the treatment effectiveness of the entire circulating water system for aquaculture wastewater [6].The combined use of different types of filter media for comprehensive wastewater treatment allows the integration of their respective treatment characteristics, achieving effective complementarity. This study constructed a three-stage aerated biological filter tower using fiber bundles, ceramic particles, and zeolite to treat wastewater from a recirculating aquaculture system. Based on the selection of aerated biological filter media and process parameter design, a wastewater treatment unit comprising a solid-liquid separator and the aerated biological filter tower was established to treat the wastewater from the recirculating aquaculture system (Table 1).The concentration of pollutants in the wastewater to be treated from the simulated recirculating aquaculture system was determined to establish optimal aeration parameters. The treated water was then tested for ammonia nitrogen and dissolved oxygen levels. Five aeration methods were selected (the air-to-liquid ratios of 1:1, 4:1, 8:1, 12:1, and 16:1) to evaluate their treatment efficacy.

Table 1. Technical Parameters of Biological Filters

Filter Type	Conventional Filter	High-Rate Filter	Tower Filter
Filter Material	Gravel, ceramic particles, etc.	Gravel, etc.	Lightweight materials, etc.
Hydraulic Loading $m^3/(m^2/d)$	0.9-3.7	9-36	16-97
Recirculation	None	YES	YES
Filter Bed Height (m)	1.5-2.0	2-4	8-12

3. Result

3.1. Optimized Selection of Filter Tower Packing

Conventional aerated biological filters typically employ a single filter material for wastewater treatment, which compromises the stability of purification efficiency. Therefore, this experiment selected three distinct types of fillers to combine their respective characteristics and advantages, optimizing both the choice of filter material and the internal structure of the filter.

The first-stage filter requires a packing material with low density, minimal moisture loss, and excellent biochemical stability to prevent erosion and degradation [7]. A newly developed

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polyester fiber was selected here, featuring a particle diameter of 8 cm and a length of 45 cm. The bristle density is approximately 80 bristles per centimeter, with a specific surface area of 1010 m^2/g. Its characteristics include lower density, reduced hydraulic resistance, lower backwash energy consumption, and larger specific surface area. Furthermore, since its axial orientation is fixed by the brush shaft, it prevents filtrate loss during backwashing. For the secondary filter media, ceramic granules offer advantages such as lightweight structure and abundant porosity. These properties create suitable growth conditions for adsorbent bacteria, enhancing oxygen transfer efficiency and increasing bacterial activity [8]. Ceramic particle sizes can be selected according to specific requirements. Particles of different sizes are matched to ensure uniform void distribution between them. This continuously fragments the airflow into fine bubbles during filtration, increasing the contact area with water and enhancing wastewater purification efficiency. The tertiary filter employs zeolite media. Due to its inherent composition and structure, zeolite selectively adsorbs ammonium ions, making it widely adopted for treating wastewater with high ammonia nitrogen content. Additionally, molecular sieves exhibit superior impact resistance due to their surface layer featuring increased porosity and denser structure. Compared to conventional carbon adsorbents, molecular sieves offer lower cost and easier production, demonstrating significant development potential.

In the filter media loading setup, the primary biological filter tower used polyethylene frames to secure the fiber bundle media, which prevented the accumulation of media from causing reactor blockage. The experiment used a vertically suspended ring method, distributing it evenly in the filter tank at a concentration of 70 pieces/m^3.In the secondary and tertiary filter towers, since ceramic pellets and zeolite pellets are used, the particle size of the filtration materials gradually decreases during the flow process, which can thus address problems such as system blockages caused by using fillers of the same size in conventional biochemical filtration. Each biological filter tower's filler is divided into three layers according to the particle size of the filter material to prevent internal collapse and pore formation caused by differences in particle size, which would reduce filtration efficiency. Stainless steel mesh sheets are used to separate each filter layer of different particle sizes.

3.2. Optimization of Filter Aeration System

The operational characteristics of the aeration system have a significant impact on the oxygenation effect in water and equipment with low energy consumption, high efficiency and convenient maintenance and management is usually selected. According to the spatial position of the aeration system and the packing, Filter Aeration System can be divided into external packing aeration and internal packing aeration. Internal aeration, which is generally more efficient, is usually chosen as the engineering design option. It can enhance microbial activity, reduce the consumption of dissolved oxygen, and is also beneficial for pollutant removal, thereby improving the system's effluent performance. The biological filtration combined process was optimized on the aeration device, utilizing a nano-aeration disc for aeration. At the bottom of the biological filtration tank, a spiral-type powerful air pump was employed to deliver air to the aeration disc. By utilizing the characteristics of nano-aeration plates, which produce uniform and small bubbles, it can effectively improve the issues of large aeration bubbles and uneven air mixing commonly seen in conventional perforated pipes, while also preventing problems such as the detachment of bottom biofilms caused by excessively large bubbles. The experiment used an airflow meter to control the intake air volume, while simultaneously sending air and liquid in the same direction into the biofilter tower. As it passes through the filter, the filter's obstruction can enhance the contact between air and water, thereby improving the aeration effect.

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3.3. Pollutant Removal Efficiency under Different Gas-Liquid Ratios

Dissolved oxygen in a biological filter is an important factor determining the efficiency of advanced wastewater purification. Regulating the air-to-liquid ratio can ensure the dissolved oxygen in the water is fully utilized, thereby accelerating microbial growth and metabolism, ultimately achieving the goal of advanced wastewater purification. An appropriate gas-liquid ratios helps maintain sufficient dissolved oxygen in the reactor, promoting the growth of microorganisms and the degradation of organic matter. When the ratio of water to air is relatively large, it can cause the detachment of the biofilm, thereby reducing the system's efficiency and increasing operational costs; when the ratio of air to water is relatively small, the bacteria's ability to survive and reproduce in water is limited, making it difficult to ensure effective wastewater treatment. A reasonable air-to-liquid ratio plays a significant role in improving the treatment efficiency of aerated biological filters and reducing the operating costs of biochemical filters.This article selects nanobubble aeration tubes for the aeration equipment. During the aeration process, they produce numerous tiny bubbles and can remain in the water for a relatively long time, generating turbulence in the system. This ensures thorough mixing of the gas and liquid phases, thereby enhancing the oxygen transfer efficiency of the aeration.After the system membrane is successfully installed, because the dissolved oxygen concentration in the incoming water directly affects the dissolved oxygen concentration in the biological filter towers along the way, aeration is first carried out in the primary biological filter tower, allowing air and water to flow parallel into the filter tower, thereby increasing the dissolved oxygen concentration within the tower.The influent flow of the control system is 1 m^3/d, with an HRT of 6 hours. Within the temperature range of 24 to 27°C and a pH range of 7.2 to 7.5, the changes in water dissolved components are analyzed under different air-to-liquid ratios.

3.4. Operating Performance under Different Gas-Liquid Ratios

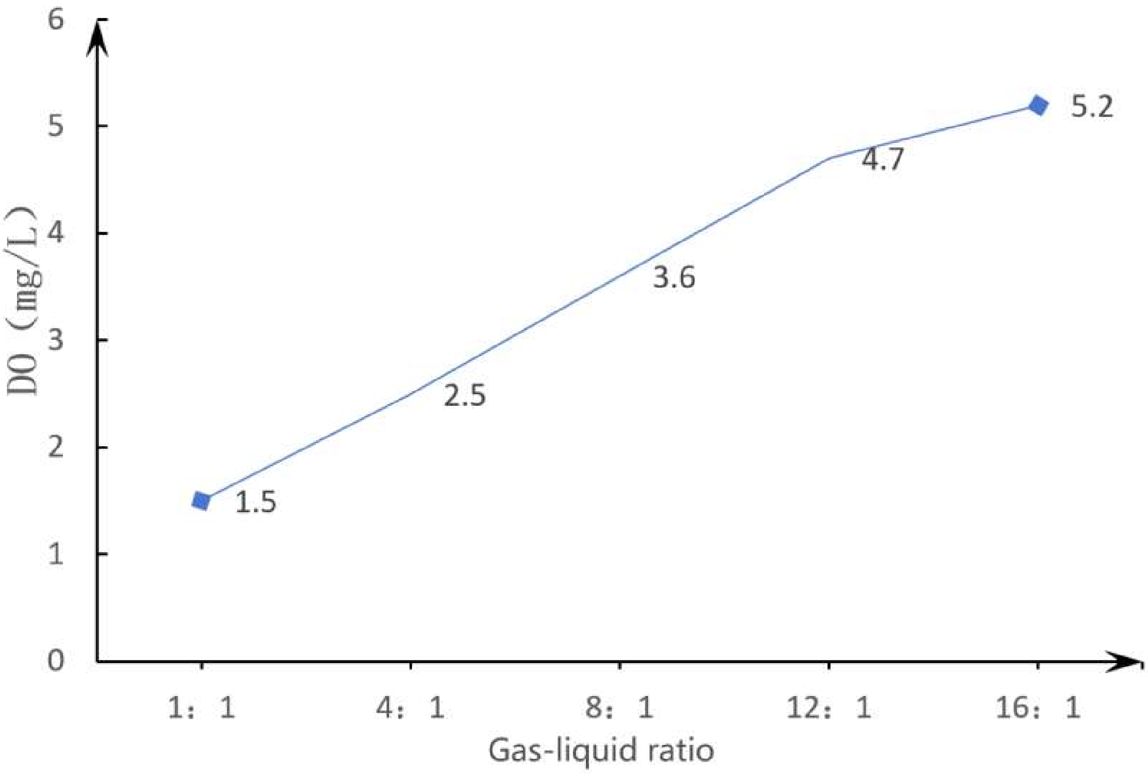

Figure 1. Dissolved oxygen concentration in the effluent under different gas-liquid ratio conditions

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Under the condition of keeping the above operation parameters unchanged, experiments were conducted at air-liquid ratios of 1:1, 4:1, 8:1, 12:1, and 16:1 for five different working conditions, and after each condition reached stable operation, one sample was taken. The effect of the gas-liquid ratio on DO is shown in Figure 1: When the gas-liquid ratio increases from 1:1 to 12:1, the average DO concentration rises from 1.5 mg/L to 4.7 mg/L, with a relatively rapid increase. Increasing the ratio from 12:1 to 16:1 only raises DO to 0.5 mg/L, then the rate of DO increase slowed down, indicating that the dissolved oxygen concentration in water has reached a certain saturation level. Therefore, a gas-liquid ratio of 12:1 can be selected as the operational condition. The experimental results also show that when the gas-liquid ratio increases from 1:1 to 12:1, the removal efficiency of NH_3-N shows an upward trend. The ammonia-nitrogen concentration in the effluent can be reduced from 5 mg/L to 2.5 mg/L. Considering these factors, controlling the gas-liquid ratio at 12:1 allows this process to achieve better ammonia-nitrogen removal performance.

4. Conclusion

Recirculating aquaculture boasts numerous advantages such as water conservation, environmental friendliness, economic high yield, and sustainability. To address issues in recirculating aquaculture wastewater, such as high organic matter content and elevated nitrogen and phosphorus levels, a combined process consisting of three serially connected biological aerated filters using polyester fiber, ceramic granules, and zeolite as filter materials was established as the wastewater treatment unit for recirculating aquaculture. Preliminary experiments were conducted to evaluate the efficiency of this process, exploring the optimal gas-liquid ratio conditions for the composite biological aerated filtration system. The removal efficiency of the three-stage biological aerated filtration system under various conditions was also investigated. The results showed that when the gas-liquid ratio in the biological aerated filter was controlled at 12:1 while maintaining the experimental temperature at 25℃ and under identical inlet water quality conditions, the dissolved oxygen content increased, indicating a better overall ammonia nitrogen removal effect.

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