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Application Study of Integrated Treatment Device for Treating Aquaculture Tail Water

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Abstract

To reduce the pollution load of aquaculture tail water and improve the quality of the aquaculture water environment, this study constructed an integrated treatment device. This device utilizes the complementary and synergistic effects of inclined plate sedimentation, biochemical reaction, and activated carbon filtration processes. The effectiveness of the device in purifying aquaculture tail water and its adaptability to changes in water quality were evaluated and analyzed. The results showed that, under continuous operation for processing low concentration tailwater (24 hours), the removal rates of suspended solids and permanganate index could not be calculated due to low content in the tailwater. The total phosphorus removal rate ranged between 9% and 22%, and the total nitrogen removal rate was around 25%. For high concentration tailwater (48 hours), the removal rate of suspended solids ranged from 18% to 40%, the total phosphorus removal rate was between 12% and 32%, the total nitrogen removal rate was maintained between 5% and 18%, and the removal rate of permanganate index ranged from 4% to 16%.

Keywords: Aquaculture Tail Wate; Integrated Treatment Device; Water Purification

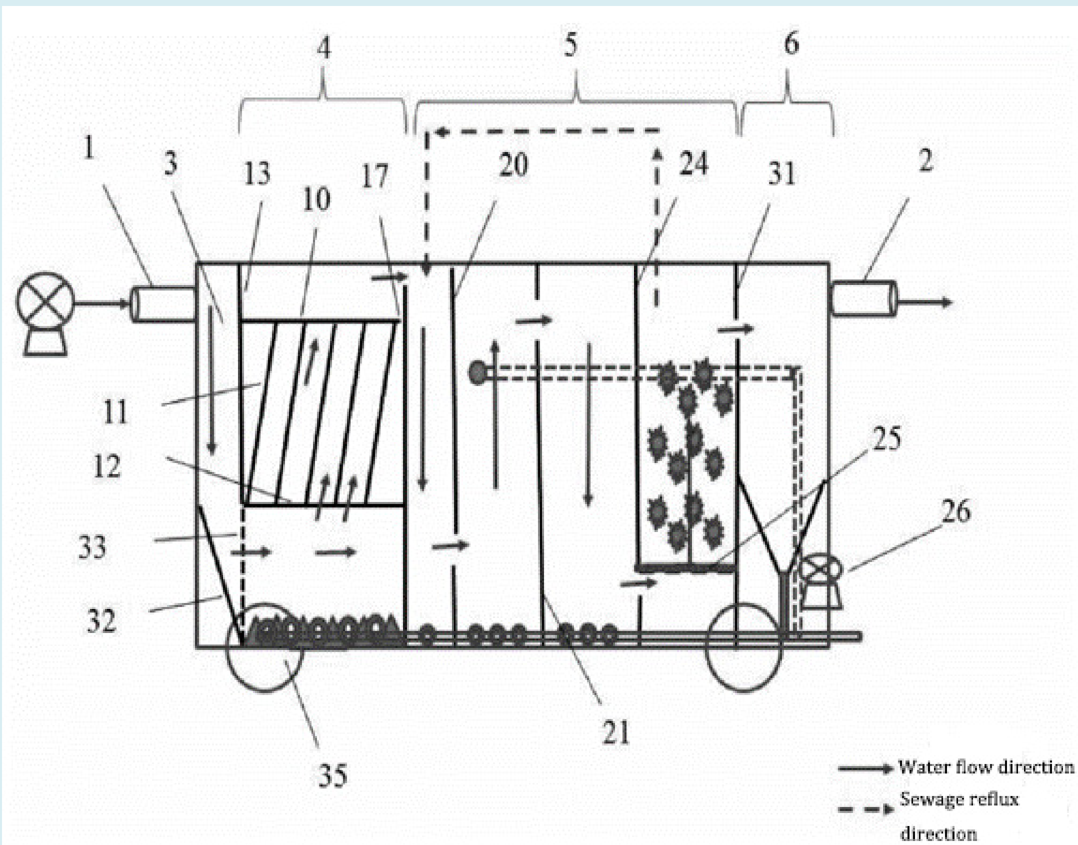
Introduction

Intensive aquaculture has brought about increasingly prominent farming problems. The traditional aquaculture practices are often inefficient, resulting in the generation of significant amounts of tail water. The direct discharge of untreated tail water will bring significant environmental pressure [1,2]. Residual bait, feces and other culture wastes from tail water continuously enter the natural environment [3,4], resulting in the accumulation of nitrogen and phosphorus in the water. The rapid deterioration of aquaculture water quality leads to a series of aquaculture diseases and reduced farm efficiency [5-8]. Jiangsu Province has issued the "Discharge standard of water from aquaculture ponds" (DB32/4043-2021) to enhance the ecological and healthy aquaculture methods, strengthen ecological environment protection in fishery waters, and promote standardized practices for the discharge or recycling of pond aquaculture effluent. The first-level emission standard stipulates that the concentration of suspended solids must not exceed 40 mg/L, the pH range should be between 6 and 9, the total nitrogen concentration must not exceed 3.0 mg/L, the total phosphorus concentration should not exceed 0.4 mg/L, and the permanganate index must not exceed 15 mg/L. Currently, aquaculture tailwater is primarily treated using multi-stage combination processes such as the 'three pools and two dams' method [9], artificial wetlands [10], and other treatment facilities. However, these methods have significant drawbacks, including a large footprint, limited effectiveness in winter, and the need for professional operation and maintenance, which requires highly skilled farmers [11]. To address the aforementioned issues and the specific characteristics of aquaculture tailwater quality, this study independently developed an integrated tailwater purification device. This device utilizes the complementary and synergistic effects of slant plate sedimentation, biochemical reaction, activated carbon filtration and other processes, including on-site evaluation of its purification capacity, in order to achieve the high efficiency of the removal of pollutants in the aquaculture tailwater. This research aims to provide a technological reference for the new green aquaculture mode of tailwater treatment unit, contributing both theoretical insights and technical support for optimizing and applying integrated tailwater purification devices.

Material and Method

Equipment Structure

The process flow of the integrated treatment device (hereinafter referred to as "device") designed in this study is shown in Figure 1. The device includes an outer box and an internal treatment box, with a water inlet and outlet at the left and right ends, respectively. The internal treatment box is located inside the outer box and consists of a water distribution area, a primary sedimentation area, a biochemical reaction area, and a secondary sedimentation area, arranged in that order from left to right. The main body of the equipment is made of steel, with overall dimensions of 213 cm × 115 cm × 165 cm and an effective operating volume of 2000 liters.



Note: 1- water inlet, 2- water outlet, 3- water distribution area, 4- initial sedimentation area, 5- biochemical reaction area, 6- secondary sedimentation area, 7- pre reaction area, 8- anaerobic area, 9- hypoxia area, 10- upper baffle, 11- diagonal flow plate, 12- lower baffle, 13- first vertical plate, 14- first sludge pipe, 15- sludge hopper, 16- aerobic area, 17- second vertical plate, 18- second sludge pipe, 19- third sludge pipe, 20- third vertical plate, 21- fourth sludge pipe, 22- fourth vertical plate, 23- packing box, 24- fifth vertical plate 25- exhaust duct, 26- blower, 27- funnel shaped sludge hopper, 28- sludge reflux port, 29- sludge discharge port, 30- flocculant feeding port, 31- sixth vertical plate, 32- baffle plate, 33- slot plate, 34- water pump, 35- movable wheel.

Figure 1: Schematic diagram of device structure.

Experimental Site

The test site is located at Jiangsu Kuntai Agricultural Development Co., Ltd. The tail water used for the experiment comes from two sources: outdoor pond No. 2, which has been used for aquaculture activities since this year and is dominated by Mylopharyngodon piceus (a low-concentration pollutant), and indoor pond No. 1, also under aquaculture activities since this year and dominated by Myxocyprinus asiaticus (a high-concentration pollutant).

Running Time

The first phase of this test began on August 22, 2023 and ended on August 26, 2023 and lasted five days; the second phase began on November 2, 2023 and ended on November 4, 2023 and lasted three days.

Operational steps

Filler Pre-Treatment

The selected filler is repeatedly rinsed with tap water to remove impurities, then soaked in water overnight. The soaked filler is then packed in nylon mesh bags, ensuring each bag contains an equal volume of filler.

Filling

The aquaculture tail water integration device mainly includes a water inlet, sedimentation tank, biological purification tank, packing filter tank, and water outlet. According to the test arrangement, activated carbon and stone were selected as the filler. The filler was placed in the packing filter tank using the regular loading method. Commissioning of water intake.

Use the pump to transfer the breeding tail water into the packing filter pool. After 2 hours of continuous operation, turn off the inlet and outlet water valves.

Water Sampling and Testing

The first and second tests were conducted at t=0h, 6h, 12h, and 24h. Water samples were collected from both the inlet and outlet of the aquaculture tail water integration device to measure five indicators: pH, permanganate index, suspended solids, total nitrogen, and total phosphorus.

Sample Testing and Evaluation

The indicators in this study were determined according to the Methods of Analysis for Water and Wastewater Monitoring (Fourth Edition) [12]. COD, TN, TP, and suspended solids were measured within 24 hours after acidification of the collected samples (pH was detected in the field). COD was determined by the dichromate method, TN by UV spectrophotometry with alkaline potassium persulfate digestion, and TP by ammonium molybdate spectrophotometry. The water quality was analyzed and evaluated according to the Discharge Standard of Water from Aquaculture Ponds (hereinafter referred to as the “discharge standard”).

Statistical Analysis

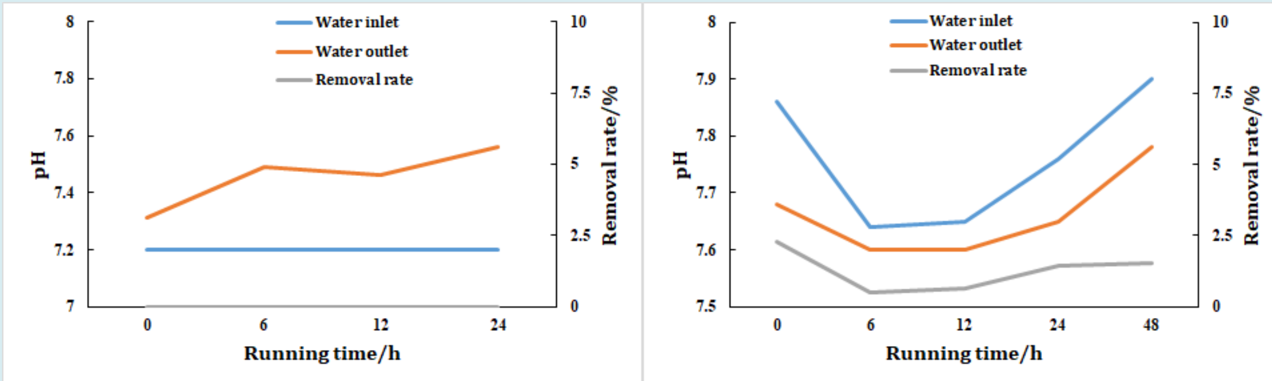
All statistical analyses were carried out with SPSS 20.0 (SPSS Inc., Chicago, IL, USA).

Results and Discussion

pH

Stabilizing pH within a certain range is beneficial for the growth of aquatic organisms [13]. When the pH of the water body is lower than 5, the resulting acidic environment can cause acidosis in fish, leading to protein denaturation, organ failure, and ultimately, death [14]. For instance, the U.S. Environmental Protection Agency stipulates that the pH discharge standard for aquaculture wastewater is 6 to 9, while Australia specifies a pH discharge standard of 5 to 9. Analysis of Fig. 2 reveals that the device shows good adaptability to pH values when treating tail water with low pollution concentration. Under continuous operation (24 hours), the pH value at the outlet remains stable below 7.6, meeting the first-class emission standard (6-9). Additionally, the device demonstrates good stability in response to fluctuations in the pH value of tail water with different pollution concentrations. After 48 hours of continuous operation, the pH value at the outlet remains stable below 7.7, still meeting the first-class emission standard. This stability is achieved by cultivating microbial communities through bio-rope and bio-balloon, which utilize microorganisms to produce organic acids during the degradation of organic matter, thereby reducing the pH value of the water [15].

Activated carbon is primarily used for the adsorption of organic matter and gases, and not directly for pH regulation. However, during water treatment, activated carbon may indirectly affect the pH of water bodies. In the process of adsorbing organic matter, some acids may be released, thus influencing the pH of the water bodies [16,17] (Figure 2).



(Left: Low concentration, Right: High concentration)

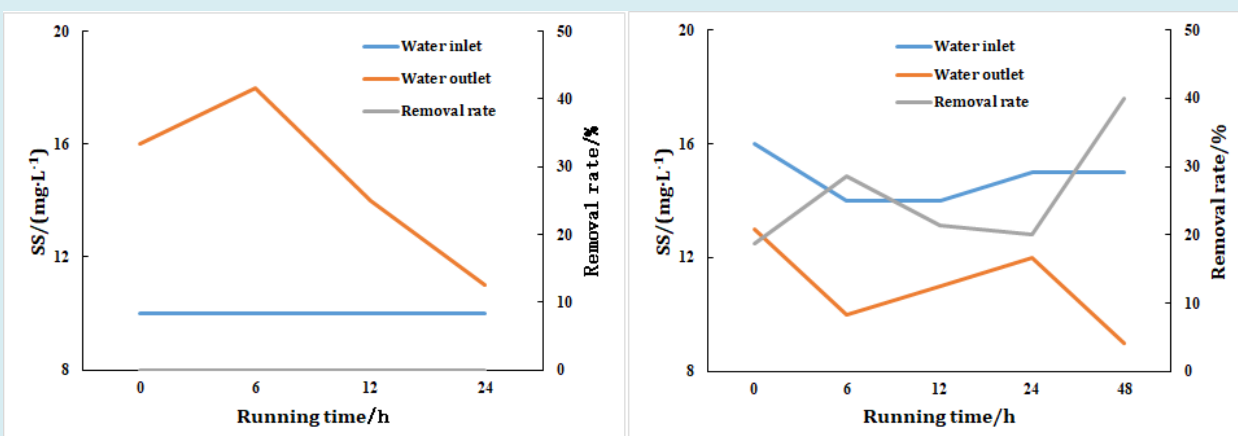
Figure 2: Changes in pH.

Suspended Solids

The effects of suspended solids on aquatic animals are multifaceted. They can reduce water clarity and affect photosynthesis, thereby impacting the growth and primary productivity of aquatic plants [18]. Suspended solids can also clog the gills of fish, affecting their respiratory function and leading to hypoxia and physiological stress [19]. Furthermore, they significantly reduce the survival and growth rates of juvenile fish [20].

From the analysis of Figure 3, it can be seen that when treating low-pollution tail water, the device's suspended solids concentration at the outlet first rises and then falls. This is because the suspended solids in the tail water are too low and do not reach the pollution standard, while the filter packing is not cleaned. In the treatment of highly polluted tail water, the removal rate of suspended solids shows a steady increase (from 18% to 40%), and the concentration of suspended solids at the effluent outlet is below 13 mg/L, which meets the first-class discharge standard.

The device uses gravity to precipitate the suspended matter to the bottom of the water by setting up a sedimentation zone and a secondary sedimentation zone [21]. Additionally, the porous structure and high specific surface area of activated carbon can effectively adsorb and remove dissolved organic matter, and physically intercept some smaller suspended particles [22], thus greatly reducing the concentration of suspended matter (Figure 3).



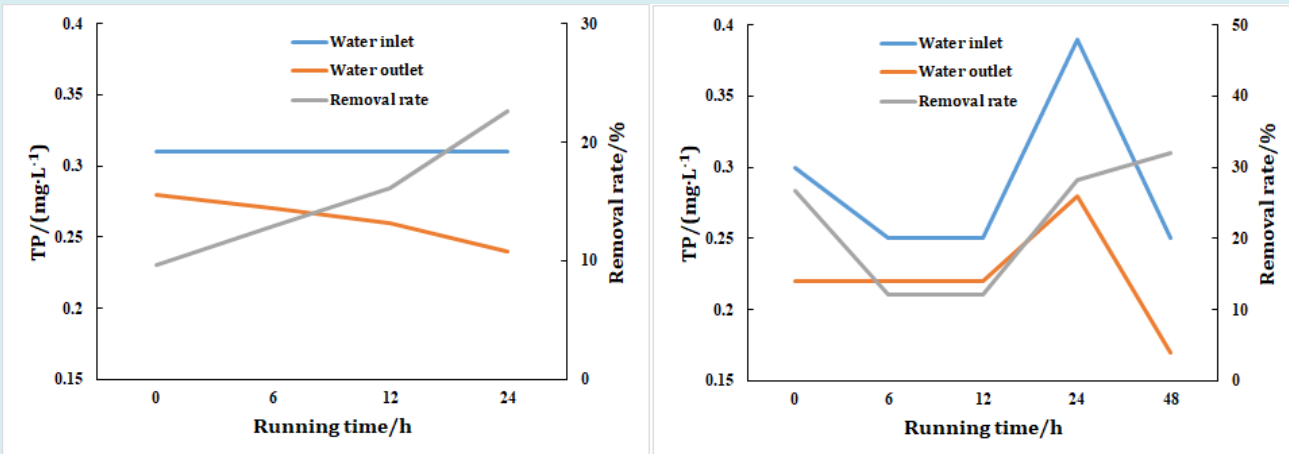
(Left: Low concentration, Right: High concentration).

Figure 3: Changes in suspended matter.

Total Phosphorus

Total phosphorus is one of the major factors of eutrophication in water bodies [23]. High concentrations of phosphorus can lead to eutrophication, triggering algal blooms that greatly affect the living environment of aquatic organisms (fish, invertebrates, etc.). The device has high purification efficiency for total phosphorus in tail water of different concentrations, maintaining removal rates between 10% and 30% (Figure 4). With increased operating time (up to 48 hours), the removal rate remains stable, with only brief decreases possibly due to the microbial community's adaptation process to high phosphorus concentrations [24].

The microbial treatment of total phosphorus is an effective method to remove phosphorus by incorporating it into microbial cells through anaerobic/aerobic processes [25]. The device is equipped with anaerobic and aerobic zones to better cultivate the microbial community (Figure 4).



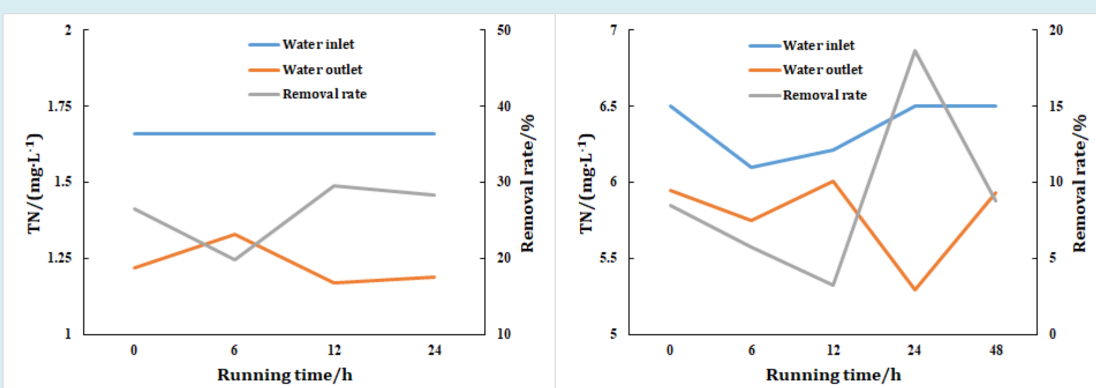
(Left: Low concentration, Right: High concentration).
Figure 4: Changes in total phosphorus.

Total Nitrogen

Total nitrogen has an important impact on aquatic animals and ecosystems. High concentrations of total nitrogen can lead to eutrophication, triggering algal blooms, which consume oxygen in the water and cause hypoxia. The decomposition of these blooms further consumes oxygen, affecting the survival of aquatic animals by impacting their respiratory and immune systems [26]. High total nitrogen levels can also affect the population structure and number of zooplankton, disrupting the entire food chain and altering fish population structures [27].

Analysis of Figure 5 shows that the removal rate of total nitrogen by this device is stable at about 25% for low concentrations (1.6 mg/L). For high concentrations (6.21-6.5 mg/L), the removal rate is slightly lower, at less than 20%. This difference is likely due to the limited effectiveness of activated carbon in removing total nitrogen, as nitrogen typically exists in forms such as ammonia, nitrates, and nitrites, which are not easily adsorbed by activated carbon [28].

Enhancing the device by adding fillers like zeolite, which can adsorb and ion-exchange, may effectively remove ammonia nitrogen and nitrates, thereby reducing the total nitrogen concentration [29] (Figure 5).



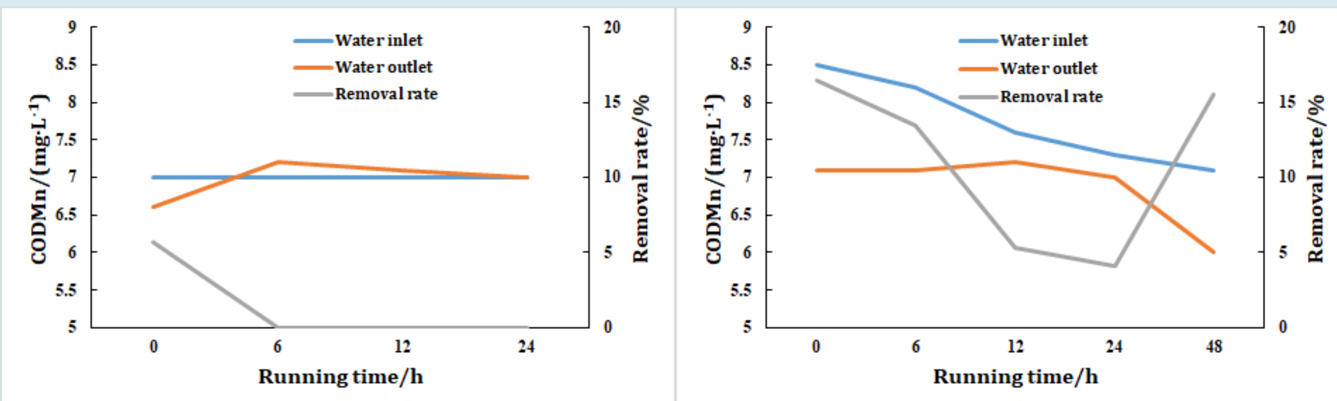
(Left: Low concentration, Right: High concentration).
Figure 5: Changes in total nitrogen.

Permanganate Index

The permanganate index is an important indicator of the amount of organic and reducing substances in water [30]. Excessive levels of the permanganate index can have acute toxic effects on aquatic animals, leading to death or physiological stress; long-term exposure to high permanganate index levels can have chronic toxic effects on the physiological functions and immune systems of aquatic animals.

As seen in Figure 6, under continuous operation of the device (24h), the removal rate of the permanganate index cannot be calculated due to its low content in the tail water, and the permanganate index at the outlet remains stable at 7.2 mg/L or less, meeting the first-class discharge standard. In Figure 8, under continuous operation of the device (48h), the removal rate of the permanganate index ranges from 4% to 16%, with the permanganate index at the outlet also stable at 7.2 mg/L or less, all meeting the primary discharge standard.

This efficiency is due to the cultured microbial community removing the permanganate index through multiple mechanisms, including biodegradation (where organic and reducing substances are metabolized into harmless substances), biosorption (where these substances are adsorbed onto the cell surface), and biotransformation (where enzymes convert these substances into other forms) [31-34] (Figure 6, Table 1).



(Left: Low concentration, Right: High concentration).
Figure 6: Changes in permanganate index.

Data number	Ph	Suspended solids	Total phosphorus	Total nitrogen	Permanganate index
		mg/L	mg/L	mg/L	mg/L
l-ct	7.2	10	0.31	1.66	7
l-t0-1	7.3	16	0.28	1.22	6.6
Removal rate/%	0	0	9.68	26.51	5.71
l-t6-1	7.5	18	0.27	1.33	7.2
Removal rate/%	0	0	12.9	19.88	0
l-t12-1	7.5	14	0.26	1.17	7.1
Removal rate/%	0	0	16.13	29.52	0
l-t24-1	7.6	11	0.24	1.19	7
Removal rate/%	0	0	22.58	28.31	0
h-t0-0	7.9	16	0.3	6.5	8.5
h-t0-1	7.7	13	0.22	5.95	7.1

Removal rate/%	2.3	18.75	26.67	8.16	16.48
h-t6-0	7.6	14	0.25	6.1	8.2
h-t6-1	7.6	10	0.22	5.75	7.1
Removal rate/%	0.5	28.57	12	5.74	13.41
h-t12-0	7.7	14	0.25	6.21	7.6
h-t12-1	7.6	11	0.22	6.01	7.2
Removal rate/%	0.7	21.43	12	3.22	5.26
h-t24-0	7.8	15	0.39	6.5	7.3
h-t24-1	7.7	12	0.28	5.29	7
Removal rate/%	1.4	20	28.24	18.62	4.11
h-t48-0	7.9	15	0.25	6.5	7.1
h-t48-1	7.8	9	0.17	5.93	6
Removal rate/%	1.5	40	32	8.77	15.49

Note: l-indicates low-pollution aquaculture tail water, h-indicates high-pollution aquaculture tail water; t0-sampling time is 0h, 0-water samples taken at the inlet of aquaculture tail water integration device, i.e., raw water; 1-water samples taken at the outlet of aquaculture tail water integration device.

Table 1: Water quality test results.

Conclusion

The integrated treatment device for aquaculture tail water shows impressive adaptability in handling various pollutants. The data showed that in low concentration polluted water, under continuous operation for 24 hours, the outlet suspended solids stabilized below 18 mg/L, total phosphorus below 0.28 mg/L, total nitrogen below 1.33 mg/L, and the permanganate index below 7.2 mg/L. In high concentration polluted water, under continuous operation for 48 hours, the outlet pH stabilized below 7.7, suspended solids below 13 mg/L, total phosphorus below 0.28 mg/L, total nitrogen below 6.0 mg/L, and the permanganate index below 7.2 mg/L. All these values comply with the first-class discharge standard.

Under continuous operation for 24 hours with low concentration tail water, the removal rates of suspended solids and permanganate index could not be calculated due to their low content in the tail water. The total phosphorus removal rate was between 9% and 22%, and the total nitrogen removal rate was around 25%. For high concentration tail water, under continuous operation for 48 hours, the removal rate of suspended solids ranged from 18% to 40%, total phosphorus removal rate ranged from 12% to 32%, total nitrogen removal rate ranged from 5% to 18%, and the permanganate index removal rate ranged from 4% to 16%.

The aquaculture tailwater integrated treatment device efficiently and rapidly degrades aquaculture pollution while being a low-cost solution. The device supports long-term continuous operation and offers high operability, shock load resistance, mobility, and treatment efficiency. This device effectively addresses issues in industrialized recycling aquaculture systems. However, its effect on total nitrogen removal is not significant, indicating a need for more in-depth research.

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