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Performance of sequencing microbead biofilters in a recirculating aquaculture system

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ABSTRACT

Biological filtration, or biofiltration, is the key technology in recirculating aquaculture systems. Sequencing microbead biofilters, in which the media maintains a continuous up-and-down movement, are based on traditional microbead filters but offer superior filtration properties. The performance characteristics of a sequencing microbead biofilter installed in a recirculating aquaculture system for rearing Barcoo perch at 29 ± 1 °C were examined. The total ammonia-nitrogen (TAN) concentrations and the nitrite-nitrogen concentrations during a 52-day culture period were maintained blow 1.6 mg/L and 0.9 mg/L. In order to ensure efficient biofiltration, the optimal actual application of hydraulic retention time was determined to be approximately 3–5 min. The water flow produced by the reciprocating motion of the media served to wash away suspended solids, ensuring the occurrence of optimal nitrification processes. Additionally, the reciprocating motion of the media enhanced ammonia treatment efficiency significantly by improving the transport of nutrients and nitrification activity. Compared to a static situation the ammonia removal rate increased by 27% based on the application of up-and-down reciprocating movement. The biofilm on the microbead forms as a compact, complex, and homogeneous structure, consisting of numerous microscopic thin sheets. Additionally, a multitude of pores, interstitial voids, and vertical channels were widely observed to convey obviously advantageous properties in support of fluid passage, thus enhancing mass transfer and ultimately contributing to biofiltration effectiveness. The optimum biofilm thickness for providing efficient biofiltration was determined to be approximately 70 μm for this filter.

1. Introduction

Recirculating aquaculture systems (RAS) are focused on treatment of nitrogenous wastes, optimization of oxygenation, removal of suspended solids, and control of organic compound accumulation (Brian, 2006). A biological filter is the key technology in the RAS system. Ammonia accumulation in RAS systems is controlled through water exchange and biofilters (Brian, 2006). The system is dependent upon efficient biofilters (nitrifying bacteria) capable of oxidizing the toxic ammonia produced by aquatic organisms into nitrates, which is relatively non-toxic. Microbead biofilters employ a combination of trickling and granular biological filters. Microbead filters use an expanded polystyrene bead that ranges in diameter from 1.0 to 3.0 mm. These biofilters have great potential for use in recirculating aquaculture systems because of their high efficiency, low cost, and stable performance (Timmons et al., 2006).

Conventional microbead biofilters are operated in a down flow configuration. In this configuration, influent water is distributed over the top of the media bed, and the water subsequently trickles down through the media. Gravity flow then conducts it out of the reactor vessel. Wu et al. (2008) reported a biological filtration method using 2.0 to 3.0 mm diameter beads, each with a volume of 0.2 m^3, that had an average total ammonia-nitrogen (TAN) removal rate of 172 g TAN/(m^3 day) with influent ammonia-nitrogen levels of 3.0 mg/L. In the Greiner and Timmons (1998) study, the proposed microbead filter possessed nitrification rates ranging from 512 to 2244 g TAN/(m^3 day) for influent TAN concentrations between 0.81 and 4.63 mg/L in an intensive recirculating tilapia production facility. Timmons et al. (2006) suggested that microbead filters had a safe nitrify value for designs up to approximately 1200 g TAN/(m^3 day) for warm water systems with influent ammonia-nitrogen levels from 2 to 3 mg/L. These filters are simple and reliable in form, but they possess certain limitations due to the thickness of the filter. Excessive filter thickness can cause channeling along the wall and even moderate to severe blockage. The low hydraulic retention time within the bead bed volume will, however, lead to reduced nitrification efficiencies in microbead biofiltration systems (Timmons et al., 2006). If the height of the microbead in the filtration system is too great, or if the width of the chamber is too great, the essentially free flow of water through the center region

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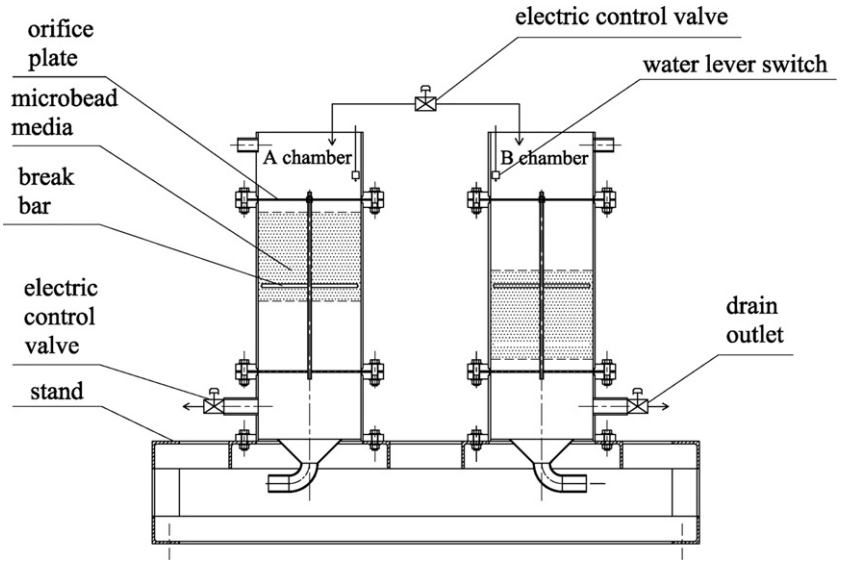

Fig. 1. Design of two-chamber sequencing microbead biofilter. While one chamber was in an inflow state, the other one was drained, proceeded by the electric control valve and water level switch in an alternating fashion.

of the filter tends to initiate water channeling. Water channeling detrimentally decreases the residing time of the reactants passing through the biofilm, thus leading to decreased nitrification activity. The force that prevents water channeling through the media forms the limiting factor for the height as well as diameter of microbead beds. Timmons et al. (2006) considered bead filters to be limited to a depth of approximately 50 cm.

The sequencing microbead biofilter is a successful design modification based on the conventional microbead biofilter concept that was patented by Holder Timmons Engineering, LLC (United States Patent Number US 2007/0056890 "Water filtration system and its use," awarded March 15, 2007). In this modified system, the microbead maintains a continuous up-and-down movement. The breaker bars are positioned in the bead bed volume in order to generate a relative displacement between microbeads, which enable the biofilter obtain the effect of self-cleaning. Microbead biofilter treatment technology is a new recirculating aquaculture water treatment method with potential for use in many commercial systems; however, information on the performance and optimization of sequencing microbead biofiltration in RAS systems is rare. This study seeks to characterize the performance of a sequencing microbead biofilter installed in RAS system, providing a useful case and operation parameter with wide potential applications.

2. Materials and methods

2.1. Equipment

The experimental sequencing microbead biofilter, as shown in Fig. 1, was set up in the Key Laboratory of Fishery Equipment and Engineering, Fishery Machinery and Instrument Research Institute, Chinese Academy of Fishery Sciences. The biofilter was divided into two chambers, designated A-chamber and B-chamber. The water flow through the filtration system was proceed by the electric control valve and water level switch in an alternating fashion, regularly switching between the vessels to enter the A-chamber or B-chamber. Thus, while the A-chamber was in the inflow state, the B-chamber was in the drainage state. Similarly, following the rise of the A-chamber water level and microbead packing layer, the B-chamber water level and bead packing both dropped. When the A-chamber water level reached the level control switch, the switchover occurs by means of the electric control valve associated with the water level switch. Conversely, while the B-chamber was in an inflow state, the A-chamber was drained. Following the rise of the B-chamber water level and microbead packing layer, the A-chamber water level and bead packing both dropped. The filter achieved the required water level and bead packing in the vessels up-and-down cycle by alternately fill and drain between the two chambers. Each chamber of the experimental filter was 30 cm in diameter and 50 cm height. The filter used expanded polystyrene beads (microbead) approximately 3.0 mm in diameter, with a density of 28 kg/m^3 and a specific surface area of 1160 m^2/m^3. The microbead packing layer was highly filled at 0.26 m, exhibiting a microbead packing volume of 0.037 m^3. The filter used a pump to carry water, while the water trickles down the microbead packing due to gravity. Aeration is not required for the filtration system during the experiment.

2.2. Experimental system and conditions

The RAS test system consisting of a 1.3 m^3 culture tank, a particle trap, swirl separators, a pump sump, a reuse pump, a sequencing microbead biofilter, and an air diffuser, is shown in Fig. 2. The bulk water was pumped from a sump (water volume, 0.2 m^3) to the tested filter after removing solid wastes by the swirl separator, and then returned to culture tank. The total water volume of the system was about 1.6 m^3. The pH value was maintained at the range of 6.8–7.2 by dosing with $NaHCO_3$. The sump was aerated with air through a diffuser so that the dissolved oxygen concentration was maintained at 6.2 ± 0.6 mg/L.

2.3. Experiment design

Generally, this experiment was carried out following three sections:

Section 1: Biofilter startup and operation (with fish).

The experimental system was seeded using 10 L of activated sludge from a treatment plant as a source of bacteria. Barcoo perch (*Scortum barcoo*, McCulloch et Waite) was reared in the culture tanks. And the production of large amounts of ammonia could offer nutrient source for nitrifier due to daily fish feeding and fish metabolism. The entire culturing cycle can be divided into the acclimation process, the shock loads process and the stable stage. During the acclimation process, the culturing load was 7 kg fish/m^3. When