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Impact of rapid impulse operating disturbances on ammonia removal by trickling and submerged-upflow biofilters for intensive recirculating aquaculture

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Abstract

Biofilters are regularly used in aquaculture production systems to remove ammonia and nitrite and are the only economically feasible ammonia removal devices in saltwater systems. Six identical 5.23 L biofilters, three trickling and three submerged-upflow filters, were operated at predetermined water quality conditions (pH 7.5, temperature 25 °C, salinity 5 ppt, TAN 1 mg/L), and then perturbed to simulate a number of possible operating disturbances, e.g. increased fish load, flushing of culture tanks, closing off of valves. Each disturbance was a controlled impulse change in ammonia concentration, temperature, pH or salinity. The maximum water quality ranges were pH 6–9, TAN 0.5–4.0 mg/L, temperature 15–35 °C, and salinity 0–10 ppt. After each disturbance, the water quality was immediately returned to the predetermined (baseline) values. The ammonia removal across the filters was monitored during the disturbance and the recovery period for loss and subsequent restoration of biofilter removal efficiency. Baseline nitrification rates resumed within 1–2 h after cessation of the shock. Some impulse shocks were temporarily detrimental to both filter types—especially low pH (−29% efficiency), low salinity (−13% to −18% efficiency), and low temperature (−11% to −13% efficiency). Raising the temperature (+9% to +12% efficiency) and TAN concentration (+0.30 to +0.36 mg/L of filter additional TAN removal) appears to be beneficial to the biofilter.

Keywords: Biofilter; Nitrification; Wastewater; Aquaculture; Nitrifying bacteria; Ammonia; Impulse shock

1. Introduction

Nitrifying bacteria are ubiquitous in nature. These bacteria proliferate in the presence of inorganic nitrogenous compounds such as ammonia and nitrite. Nitrifying biofilters are merely fixed media that allow the immobilization of nitrifying bacteria that use ammonia or nitrite in their metabolic and growth processes. Aquatic animals produce ammonia as a result of their metabolic processes that are then utilized by the nitrifying bacteria.

Environmental and health concerns make recirculating aquaculture an attractive technology for a clean

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and high quality source of fish protein for human consumption. Firstly, recirculating aquaculture is fish farming, not fishing, so the wild stock is inherently preserved. Secondly, recirculating aquaculture isolates the animals from any natural or artificial waterways and helps to contain any outbreak of disease. Thirdly, large quantities of high quality aquatic animals can be harvested at regular intervals, as recirculating aquaculture can maintain high biomass densities. Fourthly, water usage in recirculating aquaculture is highly conserved.

Presently, nitrifying biofilters are designed based on ammonia inlet concentrations, which is a carryover from the municipal wastewater industry where high (>10 mg/L) ammonia concentration waters are the rule rather than the exception. In fact ammonia inlet concentrations can run substantially higher: e.g. 60–170 mg N/L as NH_4^+-N feed solution from landfill leachate (Jokela et al., 2002), 35–140 mg NH_4^+-N/L simulated wastewater (Rahmani et al., 1995). In addition, since many municipal wastewaters are isolated from their surrounding environment during treatment, hydraulic retention times may be long and treatment methods may not initially be constrained by environmentally friendly measures. Thus, some researchers were able to add granular sulfur to their biofilter to treat low carbon loaded domestic wastewater from a primary clarifier derived from a municipal wastewater treatment facility (Kim et al., 2003). The sulfur was utilized as an electron donor and as media for biofilm attachment. For the most part, municipal wastewater ammonia removal is governed by zero-order kinetics (Isaacs et al., 1995).

On the other hand, for recirculating aquacultural systems, total ammonia nitrogen (TAN) concentrations below 1 mg/L seem to be the tolerable concentration limit for most fish to thrive, since it becomes toxic to many species above this limit (Brune and Gunther, 1981; Owsley et al., 1989; Twarowska et al., 1997; Hagopian and Riley, 1998). Concentrations above this cause stress, disease, and eventual death for the fish. In order to maintain a good operating environment, prompt waste solids and ammonia removal and proper aeration of culture water is essential (Twarowska et al., 1997; Skjolstrup et al., 1998). The conditions of temperature, pH, and salinity are, to a certain extent, already preset by the fish requirements. Also in recirculating aquacultural systems, there is an indication that the ammonia loading rate functions as an important additional factor in ammonia removal (Brune and Gunther, 1981). Recent research (Wells, 1997) indicates that a combination of ammonia inflow concentration and ammonia loading rate play significant roles in the amount of ammonia removal achieved.

Based on the difference noted, classical municipal wastewater design concepts may not produce the most accurate biofilter-sizing configuration for recirculating aquacultural systems and their biofilters tend to be generally larger in volume than their municipal wastewater counterparts when handling the same amounts of ammonia. Also, at these low concentrations, it appears that TAN, instead of dissolved oxygen, becomes the limiting substrate for nitrification (Guger and Boller, 1986) and first-order kinetics as well as other nitrification mechanisms govern the bacterial ammonia utilization process (Hagopian and Riley, 1998). Dissolved oxygen becomes the limiting substrate above 1 mg/L TAN, and nitrification is governed by zero-order kinetics. Due to the mutually exclusive differences in behavior between municipal wastewater and aquacultural wastewater, and hence the respective nitrifying biofilters, it is imperative to study the effects of water quality operating disturbances solely in the aquaculture context, because any parallel investigations done in municipal wastewater treatment research would not be applicable; some of these disturbances can easily have detrimental consequences to recirculating aquacultural system. Thus, the resulting impact of and recovery from disturbances on the nitrification efficiency of commercially available biofilter configurations should be determined and documented.

2. Objectives

1. Determine the effect of an impulse change in pH or ammonia influent concentration or temperature or salinity on ammonia removal of trickling and submerged-upflow biological filters.
2. Make recommendations to users on how impulse changes to biological filters can be managed to minimize damage to filter operation.