Available online at www.sciencedirect.com
SCIENCE DIRECT®
Aquacultural Engineering 35 (2006) 26–37
aquacultural engineering
www.elsevier.com/locate/aqua-online

Impact of positive ramp short-term operating disturbances on ammonia removal by trickling and submerged-upflow biofilters for intensive recirculating aquaculture

Catherine Lyssenko *, Fred Wheaton

Department of Biological Resources Engineering, University of Maryland, College Park, MD 20742, USA

Received 4 August 2005; accepted 5 August 2005

Abstract

Biofilters are regularly used in freshwater 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, i.e., three trickling and three submerged-upflow filters, were operated at predetermined baseline 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 positive ramp short-term change in ammonia concentration (with other water quality parameters held constant) or temperature or pH or salinity. Ammonia removal across the biofilters was monitored during the disturbance and recovery period for loss and subsequent restoration of ammonia removal efficiency. Baseline water quality to the filters was resumed at the end of each disturbance and baseline ammonia removal occurred within 1 to 2 h after end of disturbance. Ranges of variation in water quality were pH 7.5–9, TAN 1.0–4.0 mg/L, temperature 25–35 °C, and salinity 5–35 ppt. Salinity increases over a 5–10 h period reduced biofilter removal efficiency (−12 to −30% TAN removal); temperature increases, over a 1.6–10 h period, offered about a 5% increase in TAN removal while gradual TAN increases, over a 3–12 h period, although providing an approximately extra 1 mg/L of removal did not significantly change removal efficiency; and gradual pH increases, over a 3–7.5 h period, did not change biofilter removal efficiency significantly.

Keywords: Biofilter; Nitrification; Wastewater; Aquaculture; Nitrifying bacteria; Ammonia; Positive ramp short-term change

1. Introduction

Fish, such as hybrid striped bass, and other aquatic organisms excrete ammonia as a result of their metabolic processes and nitrifying bacteria use ammonia and nitrite as energy sources. These bacteria convert ammonia to nitrite and nitrite to nitrate. Fish and most other aquatic organisms are very sensitive to ammonia or nitrite concentrations, with concentrations of less than 1 mg/L of TAN (total ammonia nitrogen) being tolerable for most species (Brune and Gunther, 1981; Owsley et al., 1989; Lawson, 1995;

* Corresponding author. Tel.: +1 301 405 2223; fax: +1 301 314 9023.
E-mail address: cal25@psu.edu (C. Lyssenko).

0144-8609/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.aquaeng.2005.08.002

Twarowska et al., 1997; Hagopian and Riley, 1998; Zweig et al., 1999; Grommen et al., 2005). A standard concentration of 0.0125 mg NH_3/L (Hochheimer and Wheaton, 1997) and maximum concentration of 0.1 mg NH_3/L (Zweig et al., 1999) may be allowed for use in aquaculture. Bonn et al. (1976) recommend an upper limit of 0.6 mg ammonia/L for striped bass culture. A nitrite concentration of 1.43 mg/L produced reduced growth in silver perch (Frances et al., 1998) and 0.1 mg/L is accepted as standard for striped bass and hybrid striped bass culture (Hochheimer and Wheaton, 1997). Nitrate is a much less toxic substance for fish and acceptable limits for nitrate vary considerably by species but typically may be up to 1000 mg/L of nitrate (Lawson, 1995) and the LC_{50} can occur at 1300–1500 mg/L in some species (Grommen et al., 2005; Scott and Crunkilton, 2000; Tilak et al., 2002). Some other water quality parameters that require good management to maintain healthy hybrid striped bass are the following: between pH 6.5 and 9 (Hochheimer and Wheaton, 1997), and a slightly basic pH of 7.3 was found in a survey of the most productive hatcheries (Parker, 1984), an optimal pH of between 7.5 and 8.5 is acceptable for fry production with juveniles surviving over the range of 6.0–10.0 (Tomasso, 1997); good buffering with a mean alkalinity of 195 mg/L as calcium carbonate was found in a survey of the most productive hatcheries (Parker, 1984); dissolved oxygen levels that are at or close to saturation (Parker, 1984; Tomasso, 1997); a temperature of 25 °C has been shown to promote rapid growth (Lewis et al., 1981), about 26 °C allows concurrently high specific growth rate and food conversion efficiency (Woiwode and Adelman, 1984), and juvenile hybrids probably grow best at about 27 °C (Tomasso, 1997), implying a 25–27 °C optimum range (Hodson and Hayes, 1989); and salinities of 1.7–11 ppt for spawning fish (Karas, 1993), $\leq$10% are used for egg hatching (Tomasso, 1997), $<$15% larvae and fry (Tomasso, 1997), 2–3 ppt for larvae survival (Karas, 1993), and in the range of fresh water to near full strength sea water for fingerlings and juveniles (Tomasso, 1997; Hodson, 1989).

Biological filters are widely used in aquaculture systems to remove ammonia and nitrite from culture water. Optimal nitrifying bacteria growth occurs at about pH 7.8 (Hagopian and Riley, 1998). An overall optimal temperature for nitrification has been suggested to be about 25 °C, with a linear activity response for ammonia conversion between 7 and 35 °C (Hagopian and Riley, 1998). Although in fresh water systems there are other technologies (e.g. ion exchange) available to remove nitrite and ammonia from culture water, biological filters is the usual technique for ammonia and nitrite removal for salt water systems (Keck and Blanc, 2002), and are most often used for commercial sized fresh water systems (Watten and Sibrell, 2005). Most aquacultural biological filters consist of some type of fixed film on which nitrifying bacteria grow. Culture water is passed over the fixed film and the bacteria growing on the fixed film. The bacteria extract ammonia and convert it to nitrite hereby producing energy to drive their metabolism. Similarly other nitrifiers (e.g. Nitrobacter) convert nitrite to nitrate. Biological filters maintain low nitrite and ammonia concentrations in the culture water provided they are sized correctly and operated efficiently.

Biological filters are also used in municipal sewage treatment and operate under very different conditions. Municipal sewage treatment systems typically operate at ammonia concentrations above 10 mg/L but usually can run at substantially higher concentrations: e.g. 60–170 mg N/L as NH_4^+-N feed solution from landfill leachate (Jokela et al., 2002); and 35–140 mg NH_4^+-N/L simulated wastewater (Rahmani et al., 1995). Aquaculture filters rarely operate at ammonia concentrations above 1 mg/L (Zhu and Chen, 2002). Many authors have shown that nitrifying biological filters are typically ammonia limited below about 1 mg/L TAN (Guger and Boller, 1986; Zhu and Chen, 2002) and governed by first order kinetics (Hagopian and Riley, 1998; Zhu and Chen, 2002) and oxygen limited at high bulk ammonia concentrations (Zhu and Chen, 2002) above 1 mg/L of TAN and governed by zero order kinetics (Guger and Boller, 1986; Hochheimer, 1990; Isaacs et al., 1995). Thus, it is not always possible to directly transfer results from biological filters between the two types of applications.

Being microbial ecosystems, biological filters are vulnerable to the effects of environmental changes. In commercial aquaculture systems biological filters are often subjected to changing environmental conditions. Changes in the fish population in a system change the TAN levels while changing weather conditions can lead to changing temperatures.