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Biological treatment of low-salinity shrimp aquaculture wastewater using sequencing batch reactor

R. Boopathy*, C. Bonvillain, Q. Fontenot, M. Kilgen

Department of Biological Sciences, Nicholls State University, P.O. Box 2021, Thibodaux, LA 70310, USA

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Abstract

In order to improve the water quality in shrimp aquaculture operated under low-salinity conditions, a sequencing batch reactor (SBR) was tested for treatment of the wastewater. This water from the backwash of a single-bead filter from the Waddell Mariculture Center, South Carolina, contained high concentrations of carbon and nitrogen and was successfully treated using the SBR. By operating the reactor sequentially in aerobic, anoxic and aerobic modes, nitrification and denitrification were achieved, as well as removal of carbon. Specifically, the initial chemical oxygen demand (COD) concentration of 1201 mg l^{-1} was reduced to 32 mg l^{-1} within 8 days of reactor operation. Ammonia in the sludge was nitrified within 3 days. The denitrification of nitrate was achieved by the anoxic process and total removal of nitrate was observed.

Keywords: Sequencing batch reactor; Shrimp wastewater; Nitrification; Denitrification; Chemical oxygen demand

1. Introduction

Successful shrimp aquaculture requires maintenance of water quality conducive for the growth of shrimp. Common water quality concerns for shrimp aquaculture include inorganic suspended solids (ISS), total suspended solids (TSS), biochemical oxygen demand (BOD), dissolved oxygen (DO) and nitrogen (Sansanayuth et al. 1996; Paez-Osuna, 2001; Chen et al., 2002). Low-water-exchange aquatic animal culture systems rely on technological filtration systems in biologically and mechanically treating wastewater to reduce carbon and nitrogen (Timmons et al., 1998; Chen et al., 2002). A major drawback with this type of system is the accumulation of sludge, which must be concentrated, collected and then physically removed from the aquaculture facility (Timmons et al., 1998; Cripps and Bergheim, 2000; Chen et al., 2002).

Biological treatment of organic waste using activated sludge is a proven technology used in municipal sewage treatment facilities. Conventional anaerobic treatment processes have been used to reduce the organic carbon concentration of liquids, but these processes have not been successful in reducing both carbon and nitrogen at a reasonable cost. However, a reactor design known as a sequencing batch reactor (SBR) minimizes the capital costs by incorporating both aerobic and anaerobic processes in a single reactor (Irwine and Ketchum, 1989).

A SBR is a variation of the activated sludge biological treatment process that accomplishes equalization, aeration, and clarification in a timed sequence, in a single-reactor basin. A conventional continuous flow process requires multiple structures and extensive pumping and piping systems. The sequencing series for treatment consists of the following process stages: fill, react, settle, decant and idle (Fig. 1).

Inland shrimp aquaculture is operated under two different conditions, viz. high salinity with 30 parts per thousand (ppt) and low salinity with 3 ppt salt. Low-salinity shrimp farming is attractive because the major cost in inland shrimp aquaculture is salt water. The lower the salinity, the less the cost of farming (Browdy et al., 1995). In order to improve the water quality in shrimp aquaculture, an SBR was used for the treatment of shrimp wastewater from an intense raceway shrimp aquaculture system operating at a low salinity of 3 ppt. The objective of this study was to determine the ability to remove carbon and nitrogen from the wastewater in the SBR.

*Corresponding author. Tel.: +1 985 448 4716; fax: +1 985 493 2496.
E-mail address: biol-rrb@nicholls.edu (R. Boopathy).

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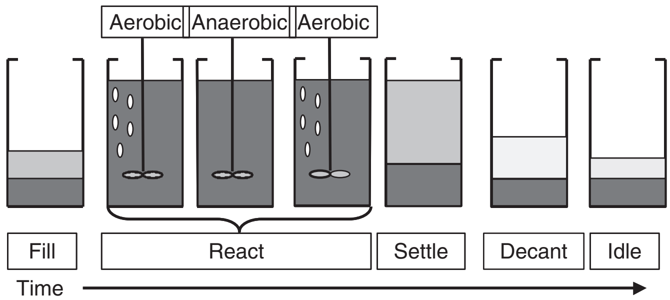

Fig. 1. Typical sequencing batch reactor operation.

2. Materials and methods

2.1. Shrimp wastewater

Shrimp wastewater from an intensive raceway system was collected from bead filter backwash at the Waddell Mariculture Center, South Carolina, and stored in sealed 3-l plastic containers at 4 °C until transferred to the SBR at Nicholls State University, Thibodeaux, Louisiana, where the research was conducted at room temperature (22 °C).

2.2. Sequencing batch reactor (SBR)

Four identical SBRs (19-l plastic buckets) were operated with shrimp wastewater. Each reactor received 4 l wastewater at the beginning of the experiment. The wastewater was aerated using air stones and mixed during aerobic operation by a stirrer motor (Model RW 20/RW 20DZM; Tekmar Company, Cincinnati, OH, USA) operating at 100 rpm. DO during aeration was 5.5 mg l^{-1}. Aeration and mixing were turned off for the system to run anoxically. DO during the anoxic phase was 0.1 mg l^{-1}. The reactors were operated aerobically for the first 2 days, then switched to anaerobic mode on day 3 and operated anoxically for 3 days before being operated in aerobic mode from day 6 to day 7. The sludge was allowed to settle on day 8 of operation. The purpose of this experiment was to optimize the aerobic and anoxic sequence for optimum removal of carbon and nitrogen. The process for nitrogen removal may be divided into two stages. In the first, aerobic stage, carbon oxidation and nitrification are combined into the single process to achieve nitrification and chemical oxygen demand (COD) removal; in the second, anoxic stage, denitrification is accomplished.

2.3. Analyses

Portions of wastewater (30 ml) were removed periodically from each reactor and centrifuged at 260*g* for 10 min and the supernatant was used for chemical analysis. Nitrite, nitrate and ammonia were analyzed periodically by colorimetric methods with a Hach water analysis kit (Hach, 1999). The COD was anal yzed using standard methods (APHA, 1998). DO, salinity and temperature were measured using a DO/salinity probe (Model No. 85-10FT, YSI, Yellow Spring, OH, USA). The pH was measured by pH probe (Model UB 10, Denver Instruments, Boulder, CO, USA).

3. Results and discussion

3.1. Characteristics of shrimp wastewater

The initial characteristics of the shrimp wastewater are given in Table 1. The wastewater contained high concentrations of carbon (assessed as COD), ammonia, nitrate and nitrite. Naturally, salinity was low, as the aquaculture was conducted at low salinity.

3.2. Reactor performance

During aerobic operation of the reactors (Fig. 2), the ammonia concentration dropped from an initial 101 mg l^{-1} to zero on day 3. At the same time, nitrate and nitrite levels both increased in the reactor. Specifically, the nitrate level increased from an initial 33 mg l^{-1} to a maximum of 88 mg l^{-1} on day 3. When the reactor was operated anoxically, the nitrate concentration gradually decreased, eventually reaching nil on day 8. During the aerobic sequence, the nitrite level increased from 260 to 371 mg l^{-1} on day 2, and during the anoxic stage there was a large drop in nitrite concentration, to 3 mg l^{-1} on day 8.

The carbon level, indicated by COD, gradually fell from the initial 1201 mg l^{-1} during both the aerobic and the anoxic phase of operation to a final 32 mg l^{-1} (Fig. 3). COD reduction was greater during the aerobic mode than in the anoxic mode. When the SBR was operating aerobically, nitrification resulted in reduction of ammonia; during anoxic operation, denitrification occurred and nitrate in the sludge was converted to nitrite, nitrous oxide and nitrogen gas, with the result that the nitrate was completely removed. The successful operation of the reactor showed that the sludge probably contained nitrifying and denitrifying organisms such as *Nitrosomonas*, *Nitrobacter*, and *Pseudomonas* able to metabolize the

Table 1
Characteristics of shrimp wastewater sludge[a]

Parameter	Concentration
Total COD (mg l^{-1})	1201 ± 36
Total solids (g l^{-1})	13.1 ± 3.9
Ammonia (mg l^{-1})	101.7 ± 6.1
Nitrate (mg l^{-1})	33.3 ± 1.4
Nitrite (mg l^{-1})	260 ± 22.7
Salinity (ppt)	2.6 ± 0.4
pH	7.8 ± 0.1

[a]Average of four analyses.

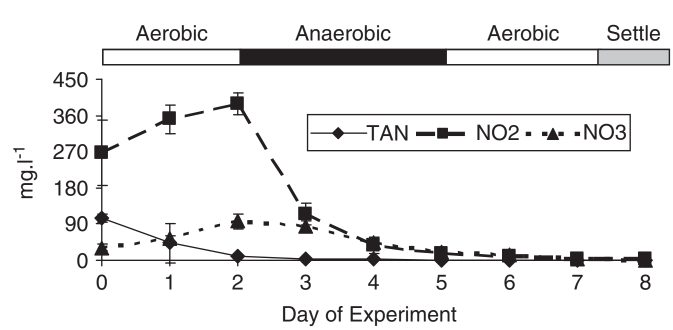

Fig. 2. Concentration of ammonia (TAN), nitrate (NO3) and nitrite (NO2) in wastewater sludge during operation of SBR for 8 days. Results are mean values for four reactors ± SD.

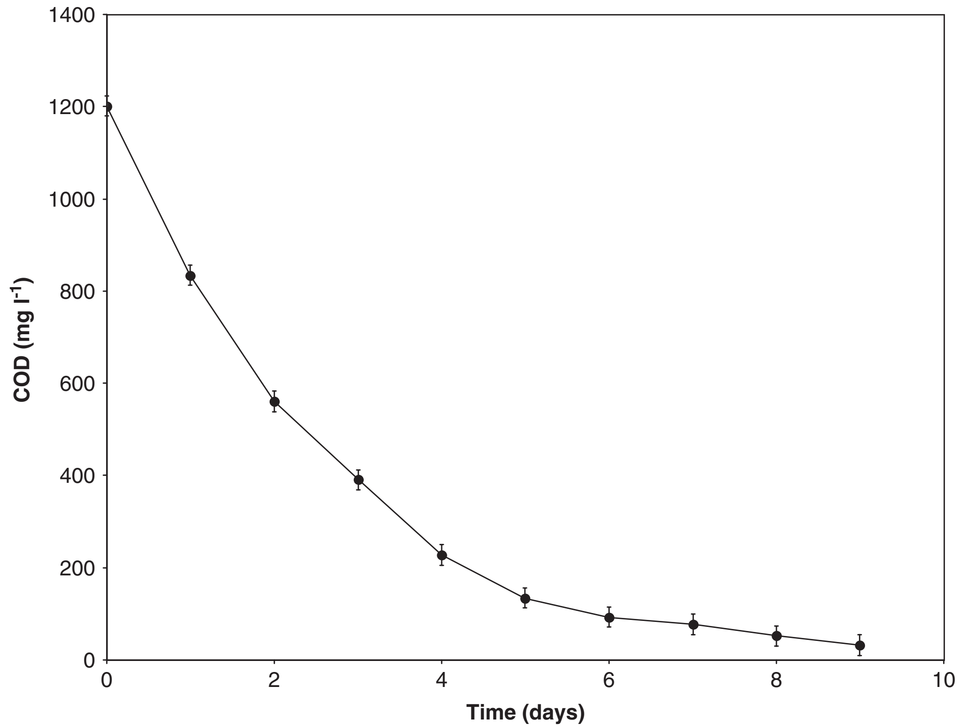

Fig. 3. COD of wastewater sludge SBR during operation of SBR for 8 days. Results are mean values for four reactors ± SD.

nitrogen in the sludge. There was no need to add specific microbes for the metabolism of carbon and nitrogen, as the SBR successfully removed both from the wastewater.

This reactor design is simple and the SBR very easy to operate. SBR systems have been used successfully for various wastewaters, including slaughterhouse wastewater, swine manure, dairy wastewater and sewage (Irwine and Ketchum, 1989; Fernandes et al., 1991; Lo et al., 1991; Willers et al., 1993; Masse and Masse, 2000). The literature shows that the wastewater problem in shrimp aquaculture can addressed by the activated sludge process, foam fractions, use of filter systems and sludge management (Hopkins, 1994; Browdy et al., 1995; Holloway, 2002). These systems are, however, costly and expensive to operate, while the very simple design of the SBR system, employing one tank for the various steps in the process, takes the place of multiple tanks in conventional treatment systems. The present study has shown that the SBR could be used to treat wastewater from an intensive shrimp raceway production system. With its aerobic process for 2 days and anoxic process for 3 days, this simple mode of operation almost entirely removed all carbon and nitrogen in the sludge wastewater. As mentioned above, the sludge clearly contained a bacterial population that not only metabolized carbon but was able to carry out nitrification and denitrification. The nitrifying organisms were active during the aerobic operation of the reactor, as evidenced by the data on removal of ammonia in the sludge wastewater (Fig. 2). Denitrifying organisms were active during the anoxic operation of the reactor, as witnessed by the levels of nitrite and nitrate dropping significantly in the anaerobic phase and eventually reaching c. $3\,\mathrm{mg\,l^{-1}}$ and zero, respectively (Fig. 2). Since the carbon was also effectively removed under both aerobic and anoxic conditions in the SBR (Fig. 3), it would be possible at the end of the operation to recycle the water.

In conclusion, it is the authors' belief that backwash from biological filters currently used in shrimp aquaculture can be directed to an SBR, which will then digest the carbon and nitrogen associated with the backwash. Once the carbon and nitrogen are digested, water can be decanted from the SBR and returned to the culture system, so that water loss will be negligible. The application of SBR technology for intensive shrimp production is an attractive alternative to various methods currently used in shrimp aquaculture.

Acknowledgments

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