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Biological Treatment of Shrimp Aquaculture Wastewater Using a Sequencing Batch Reactor

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Abstract To improve the water quality in the shrimp aquaculture, a sequencing batch reactor (SBR) has been tested for the treatment of shrimp wastewater. A SBR is a variation of the activated sludge biological treatment process. This process uses multiple steps in the same tank to take the place of multiple tanks in a conventional treatment system. The SBR accomplishes equalization, aeration, and clarification in a timed sequence in a single reactor basin. This is achieved in a simple tank, through sequencing stages, which include fill, react, settle, decant, and idle. A laboratory scale SBR and a pilot scale SBR was successfully operated using shrimp aquaculture wastewater. The wastewater contained high concentration of carbon and nitrogen. By operating the reactor sequentially, viz, aerobic and anoxic modes, nitrification and denitrification were achieved as well as removal of carbon in a laboratory scale SBR. To be specific, the initial chemical oxygen demand (COD) concentration of 1,593 mg/l was reduced to 44 mg/l within 10 days of reactor operation. Ammonia in the sludge was nitrified within 3 days. The denitrification of nitrate was achieved by the anaerobic process and 99% removal of nitrate was observed. Based on the laboratory study, a pilot scale SBR was designed and operated to remove excess nitrogen in the shrimp wastewater. The results mimicked the laboratory scale SBR.

Keywords Nitrification · Denitrification · Sequencing batch reactor · Shrimp wastewater · Organic carbon

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), chemical oxygen demand (COD), dissolved oxygen (DO), and nitrogen

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[1–6]. Low-water exchange aquatic animal culture systems rely on technological filtration systems to biologically and mechanically treat wastewater to reduce carbon and nitrogen [3, 7]. 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 [3, 7].

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 liquid, but these processes have not been successful in reducing both carbon and nitrogen at a reasonable cost. However, an innovative design known as sequencing batch reactor (SBR) minimizes the capital costs by incorporating both aerobic and anaerobic processes in a single reactor [8].

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*.

To improve the water quality in shrimp aquaculture, a SBR has been studied for the treatment of shrimp wastewater sludge from an intense raceway shrimp aquaculture system. Water is removed from recirculating systems when sludge is removed. The objective of this study was to determine if SBR treatment could be used to remove enough carbon and nitrogen from the wastewater so that the water can safely be recycled to the culture system.

Materials and Methods

Shrimp Waste Sludge

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.

Sequencing Batch Reactor (SBR)

Four identical SBRs (19-l plastic containers) were operated with shrimp wastewater. Each reactor received 4 l of wastewater at the beginning of the experiment. The reactors were aerated using air stones and the wastewater was mixed during aerobic operation at the rate of 100 rpm using a stirring motor (Model RW 20/RW 20DZM; Tekmar Company, Cincinnati, OH). Aeration and mixing were turned off for the system to run anoxically. The reactors were operated aerobically and anoxically and these modes of operation were alternated at regular intervals until the end of the experiment. The purpose of this experiment was to optimize the aerobic and anoxic sequence for optimum removal of carbon and nitrogen. SBR process for nitrogen removal may be divided into two stages as follows:

– Aerobic stage: in this stage, the carbon oxidation and nitrification are combined into the single process to achieve nitrification and COD removal.
– Anoxic stage: the second stage is an anoxic process in which denitrification is accomplished.

The results presented in this study represent average of four laboratory SBRs.

Pilot Scale SBR

Two pilot scales SBR with the capacity of 500 l were operated at the Waddell Mariculture Center, South Carolina, based on the performance of the laboratory scale SBR. The reactors were operated aerobically for the first 3 days and then operated anoxically until the end of the experiment on day 9. The performance of the reactor in carbon and nitrogen removal was reported as the average of the duplicate SBR.

Analyses

Thirty milliliters of wastewater was removed from each reactor and centrifuged at 5,000 rpm for 10 min and the supernatant was used for the chemical analysis. Nitrite, nitrate, and ammonia were analyzed periodically by colorimetric methods with a Hach water analysis kit [9]. The COD was analyzed using standard methods [10]. Total COD was analyzed using the whole sample and soluble COD was analyzed using filtered sample using 0.2-μm filter paper. The soluble COD excludes carbon from microorganisms in the wastewater and it represents the soluble organic carbon in the wastewater. The dissolved oxygen (DO), salinity, and temperature were measured using an YSI DO and salinity probe (Model No. 85–10FT, Yellow Spring, OH). The pH was measured using a pH probe (Model UB 10, Denver Instruments, Boulder, CO).

Statistical Analysis

All data were subjected to an analysis of variance (ANOVA) test ($p<0.05$) followed by a Tukey post hoc analysis when needed [11]. Total COD concentrations were analyzed using a paired *t*-test analysis ($p<0.05$) [11].

Results and Discussion

Characteristics of Shrimp Wastewater

The initial characteristic of the shrimp wastewater is given in Table 1. The wastewater contained high concentration of carbon (COD), ammonia, nitrate, and nitrite.

Performance of Laboratory SBR

Four laboratory reactors were operated under identical conditions. The reactors were operated aerobically for the first 3 days and switched to anoxic mode on day 4 and the

Table 1 Characteristics of the shrimp wastewater.*

Parameter	Concentration
Total COD (mg/l)	1593±36
Soluble COD (mg/l)	71.8±4.2
Total Solids (g/l)	33.1±3.9
Ammonia (mg/l)	83.7±6.1
Nitrate (mg/l)	31.3±1.4
Nitrite (mg/l)	250±22.7
Salinity (ppt)	28.6±0.4
pH	8.1±0.1

*Average of four analyses

reactors were operated anoxically until the end of the experiment on day 9. The initial ammonia concentration of 91 mg/l dropped to 0 mg/l on day 3 during the aerobic mode of operation (Fig. 1). At the same time, the nitrate and nitrite levels increased in the reactor, indicating the presence of nitrification reaction. Specifically, the nitrate level increased from 47 mg/l at the beginning of the experiment and reached a maximum level of 93 mg/l on day 3. When the reactor was operated anoxically the nitrate concentration gradually decreased and eventually reached 2 mg/l on day 8 of the experiment. In a similar manner, the nitrite level increased during the aerobic sequence from 235 mg/l to 401 mg/l on day 3, and during the anoxic process there was a big drop in nitrite concentration indicating the denitrification reaction in the reactor. The nitrite concentration dropped to 5 mg/l on day 9 of the experiment.

The carbon level in the wastewater is indicated by COD values. The initial COD level of 1,596 mg/l gradually dropped during both aerobic and anoxic phases of the reactor operation (Fig. 2). More CODs were removed during the aerobic mode than in the anoxic mode. The COD concentration dropped to 44 mg/l at the end of the experiment. The successful operation of the reactor showed that the wastewater contained the nitrifying and denitrifying organisms such as *Nitrosomonas*, *Nitrobacter*, and *Pseudomonas* spp., to carry out the metabolism of nitrogen in the wastewater. There was no need to add specific microbes for the metabolism of carbon and nitrogen as these were present in the shrimp wastewater and these microorganisms were not affected by the change of conditions from aerobic to anoxic modes of operation and vice versa.

Performance of Pilot Scale SBR

We believe that backwash from biological filters currently used in shrimp aquaculture can be directed to the SBR. The SBR 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 water loss will be negligible. Based on our laboratory design, two 500-l pilot scales SBR were operated in the Waddell Mariculture Center, South Carolina. The pilot scale SBR performance data are presented in Table 2. As

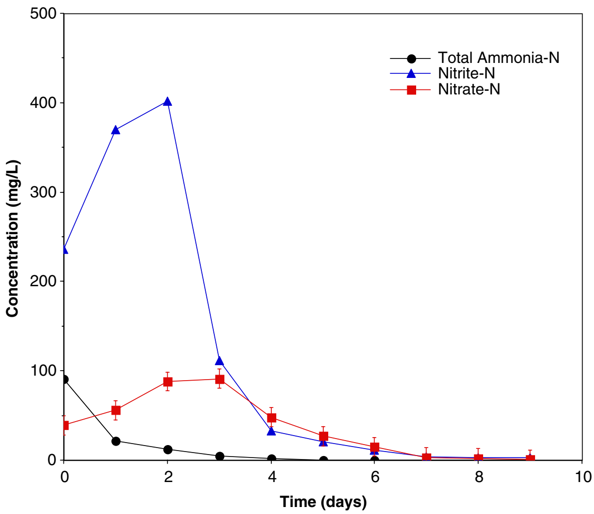

Fig. 1 The concentration of ammonia, nitrate, and nitrite in the laboratory scale SBR. The results are average with SD for four reactors

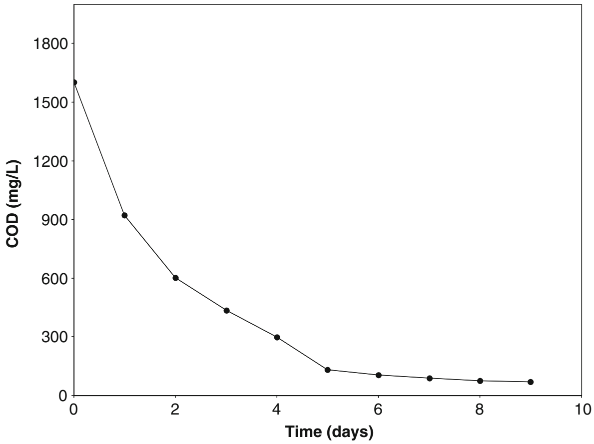

Fig. 2 COD concentration in the Laboratory scale SBR. The results are average with SD for four reactors

the results indicate, there was almost 100% removal of ammonia, nitrate, nitrite, and organic carbon (COD) from the shrimp wastewater within 7 days.

The SBR successfully removed carbon and nitrogen from the sludge sample of shrimp aquaculture wastewater. The reactor design is simple and very easy to operate. The SBR system has been successfully used for various wastewaters including slaughterhouse wastewater, swine manure, dairy wastewater, and sewage [8,12–15]. In the literature, it is shown that the wastewater problem in shrimp aquaculture is addressed by activated sludge process, foam fractions, use of filter systems, and sludge management [16, 17]. These systems are costly and expensive to operate. The SBR system is very simple in design and this process uses multiple steps in the same tank to take the place of multiple tanks in a conventional treatment system. In this study, it has been shown that the SBR could be used to treat shrimp wastewater produced from intensive shrimp raceway production system. The operation mode is simple, which includes aerobic process for the first 3 days and anoxic process for 6 days to remove 99% of carbon and nitrogen in the sludge wastewater. The sludge contained heterogenic populations of bacteria to carry out nitrification and denitrifiation reactions as well as carbon metabolism. The nitrifying organisms dominated the system during the aerobic operation of the reactor. This was evidenced by the data on the removal of ammonia in the sludge wastewater (Fig. 1). The denitrifying organisms

Table 2 Performance[a] of pilot scale SBR in treating shrimp aquaculture sludge in experiment 1.

Time(days)	Condition	NH_4	NO_2	NO_3	SCOD	TCOD
0		93.7±54.9	266±74	21.3±20.5	81.8±7.6	1593±811
1	Aerobic	55.7±42.2	661±298	27.8±14.8	56.0±23.3	1177±669
2	Aerobic	19.4±25.9	94±70	19.2±8.9	36±20.6	190±7.8
3	Aerobic	9.8±4.7	58.1±19.3	65.0	25.5±7.0	–
4	Anaerobic	3.6±8.6	46.3±12.5	20.5±4.1	4.5±17.1	–
5	Anaerobic	–	20	16.8±20.1	0	–
6	Anaerobic	–	–	–	–	–
7	Anaerobic	–	18	0	–	–

[a] Time (days) of each aerobic and anaerobic period and mean (N=2) total ammonia-nitrogen (NH_4, mg/l), nitrite-nitrogen (NO_2, mg/l), nitrate-nitrogen (NO_3, mg/l), soluble chemical demand (SCOD; mg/l), and total chemical oxygen demand (TCOD; mg/l).

dominated the system during the anoxic operation of SBR. This was supported by the fact that the levels of nitrite and nitrate dropped significantly under the anoxic phase and eventually it reached around 5 mg/l (Fig. 1). The carbon was effectively removed under both aerobic and anoxic conditions in the SBR as shown in Fig. 2. Similar results were demonstrated earlier by [6] in a SBR treating low-salinity shrimp aquaculture wastewater. At the end of the operation, the sludge can be dewatered and the water can be recycled back into shrimp production. The application of SBR technology for intensive shrimp production is an attractive alternative to various methods currently used in shrimp aquaculture.

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