J Ind Microbiol Biotechnol (2009) 36:989–992
DOI 10.1007/s10295-009-0577-0

SHORT COMMUNICATION

Biological treatment of shrimp production wastewater

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Received: 3 February 2009 / Accepted: 5 April 2009 / Published online: 25 April 2009

Abstract Over the last few decades, there has been an increase in consumer demand for shrimp, which has resulted in its worldwide aquaculture production. In the United States, the stringent enforcement of environmental regulations encourages shrimp farmers to develop new technologies, such as recirculating raceway systems. This is a zero-water exchange system capable of producing high-density shrimp yields. The system also produces wastewater characterized by high levels of ammonia, nitrate, nitrite, and organic carbon, which make waste management costs prohibitive. Shrimp farmers have a great need for a waste management method that is effective and economical. One such method is the sequencing batch reactor (SBR). A SBR is a variation of the activated sludge biological treatment process. This process uses multiple steps in the same reactor to take the place of multiple reactors in a conventional treatment system. The SBR accomplishes equalization, aeration, and clarification in a timed sequence in a single reactor system. This is achieved through reactor operation in sequences, which includes fill, react, settle, decant, and idle. A laboratory scale SBR was successfully operated using shrimp aquaculture wastewater. The wastewater contained high concentrations of carbon and nitrogen. By operating the reactors sequentially, namely, aerobic and anoxic modes, nitrification and denitrification were achieved as well as removal of carbon. Ammonia in the waste was nitrified within 4 days. The denitrification of nitrate was achieved by the anoxic process, and 100% removal of nitrate was observed within 15 days of reactor operation.

Keywords Nitrification · Denitrification · Sequencing batch reactor · Aerobic · Anoxic

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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 [3, 4, 7, 11, 13, 15, 22–25]. Low-water exchange aquatic animal culture systems rely on technological filtration systems to biologically and mechanically treat wastewater to reduce carbon and nitrogen [2, 7, 9, 17, 19, 27]. 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 [6, 8, 10, 16, 24, 27].

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 the sequencing batch reactor (SBR) minimizes the capital costs by incorporating both aerobic and anaerobic processes in a single reactor [18].

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.

In order to improve the water quality in shrimp aquaculture, a SBR has been studied for the treatment of shrimp wastewater. 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 could safely be recycled to the culture system.

Materials and methods

Shrimp wastewater

Shrimp wastewater was obtained from the Gulf Coast Marine Research Laboratory located in Ocean Spring, MS, and contained high ammonia, nitrate, and nitrite concentrations similar to an intensive shrimp raceway system [4, 5]. The characteristics of wastewater are given in Table 1. The sludge also contains important minerals such as sodium, potassium, sulfide, iron, manganese, phosphorous, and chloride, and the concentration of these minerals is 100 mg/l. These minerals fulfill the nutritional requirements of bacteria.

Sequencing batch reactor

The SBR was made of plexiglass with the dimensions of $20 \times 20 \times 25$ cm^3. The reactor was equipped with an aeration port, controller, mixing device, feeding, and decanting system. The reactor was seeded with 200 g of sludge from a bioreactor that has been in operation in our laboratory for 1 year in continuous treatment of synthetic wastewater high in nitrogen. The sludge contains 10^{-10}/ml total heterotrophic bacterial counts. Some of the bacteria in this sludge include *Nitrosomonas, Nitrobacter*, and *Pseudomonas* spp, and this sludge provided microorganisms for nitrification and denitrification reactions in the SBR. The 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. 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. Triplicate reactors were operated, and the data presented in the Sect. "Results" are the average of these three reactors. The purpose of this experiment was to optimize the aerobic and anoxic sequence for optimum removal of carbon and nitrogen. The 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 a single process to achieve nitrification and COD removal.
- *Anoxic stage* The second stage is an anoxic process in which denitrification is accomplished.

Table 1 Characteristics of the shrimp wastewater

Parameter	Concentration
Total COD (ppm)	1,555 ± 97
Total solids (ppm)	3,650 ± 119
Ammonia (ppm)	76 ± 12
Nitrate (ppm)	31 ± 6
Nitrite (ppm)	46 ± 9
Total nitrogen (ppm)	146 ± 16
pH	8.2 ± 0.3

Average of four analyses with SD

Analyses

Thirty milliliters of wastewater was removed periodically from the 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 as per standard methods [1, 14]. The COD was analyzed using standard methods [1]. The 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 of data was done using SAS [26].

Results and discussion

Performance of laboratory SBR

The reactor was operated aerobically for the first 3 days and switched to anoxic mode on day 4; the reactors were operated anoxically for 10 days and the last 2 days were operated under aerobic condition. The initial total ammonia nitrogen (TAN) concentration of 72 mg/l dropped to 0 mg/l on day 4 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 nitrite level increased from 46 mg/l at the beginning of the experiment and reached a level of 198 mg/l on day 7 (Fig. 2). When the reactor was operated anoxically, the nitrite concentration gradually decreased and eventually reached 0 mg/l on day 15 of the experiment. Similarly, the nitrate level increased during the aerobic sequence from 32 to 162 mg/l on day 8, and during the

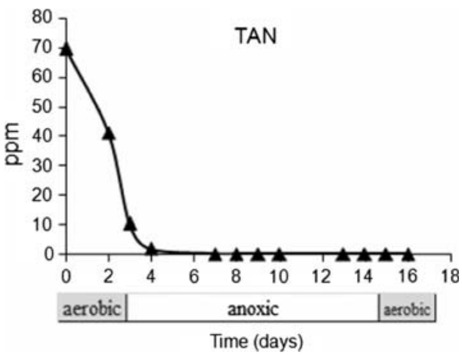

Fig. 1 Total ammonia concentration in the SBR. Data represent average of triplicate reactors

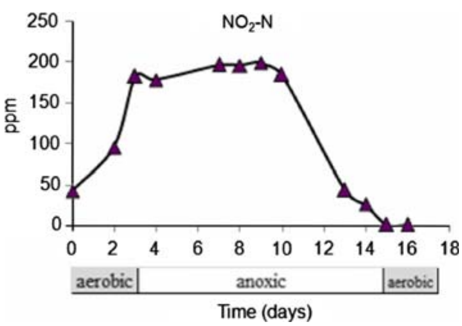

Fig. 2 Nitrite concentration in the SBR. Data represent average of triplicate reactors

anoxic process, there was a big drop in nitrite concentration, indicating the denitrification reaction in the reactor (Fig. 3). The nitrate concentration dropped to 0 mg/l on day 15 of the experiment.

All nitrogen, including TAN, NO_3, and NO_2, were combined and presented as a total nitrogen concentration in Fig. 4. The nitrogen level increased from the aerobic to anaerobic stage as all ammonia were nitrified to nitrate, and during anaerobic operation of SBR, the nitrogen concentration was decreased significantly, resulting in 100% removal of nitrogen in the wastewater within 16 days of reactor operation. The SBR also removed the organic carbon (COD) in the reactors, which dropped from 1,555 mg/l at the beginning of SBR operation to 212 mg/l at the end of the experiment on day 16, resulting in 82% removal of carbon in the system (data not shown).

The successful operation of the reactor showed that the wastewater contained 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 microbial seed used in this study, and these microorganisms were not affected by the change of conditions from aerobic to anoxic modes of operation and vice versa.

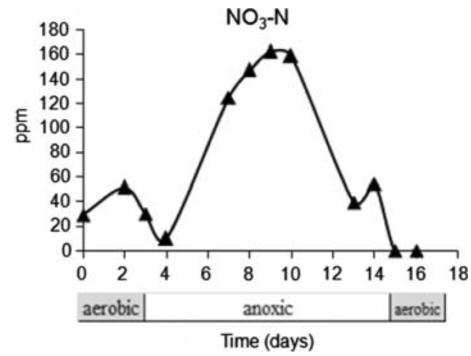

Fig. 3 Nitrate concentration in the SBR. Data represent average of triplicate reactors

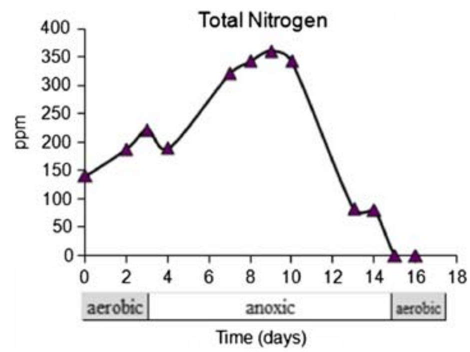

Fig. 4 Total nitrogen concentration in the SBR. Data represent the average of triplicate reactors

The SBR successfully removed carbon and nitrogen from the 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 [12, 18, 20, 21, 28]. The literature shows that the wastewater problem in shrimp aquaculture has been addressed by an activated sludge process, foam fractions, use of filter systems, and sludge management [6, 16, 25]. 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 in a way similar to the intensive shrimp raceway production system. The operation mode is simple and includes an aerobic process for the first 3 days and an anoxic process for 10 days to remove 100% of the nitrogen in the sludge wastewater. The inoculum contained heterogenic populations of bacteria to carry out nitrification and denitrification 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 wastewater (Fig. 1). The denitrifying organisms 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 reached 0 mg/l (Figs. 2, 3). Similar results were demonstrated earlier by Boopathy et al. [4] 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. Although the treatment time was slightly longer (15 days), in the shrimp industry this is considered an optimal time for waste treatment because the shrimp production time is 3–4 months, and in between two harvest cycles, there is a 20-day waiting period for the shrimp larva to grow. During this waiting period, the wastewater from previous shrimp harvests can be treated using the SBR system shown in this study, and hence it is feasible to use this technology in the shrimp industry. The application of SBR technology for intensive shrimp production is an attractive alternative to various methods currently used in shrimp aquaculture.

Acknowledgments This work was supported by funds from the US Department of Agriculture, Cooperative State Research Service of Marine Shrimp Farming Program. We thank Heidi Atwood of Waddell Mariculture Center, South Carolina, for providing the wastewater for the study.

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