Effects of temperature, salinity, and carbon: nitrogen ratio on sequencing batch reactor treating shrimp aquaculture wastewater

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Abstract

In order to improve the water quality in the shrimp aquaculture, we tested a sequencing batch reactor (SBR) 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 pH correction, aeration, and clarification in a timed sequence, in a single reactor basin. This is achieved in a simple tank, through sequencing stages, which includes fill, react, settle, decant, and idle. The wastewater from the Waddell Mariculture Center, South Carolina was successfully treated using a SBR. The wastewater contained high concentration of carbon and nitrogen. By operating the reactor sequentially, viz, aerobic, anaerobic, and aerobic modes, nitrification and denitrification were achieved as well as removal of carbon. We optimized various environmental parameters such as temperature, salinity, and carbon and nitrogen ratio (C:N ratio) for the best performance of SBR. The results indicated that the salinity of 28–40 parts per thousand (ppt), temperature range of 22–37 °C, and a C:N ratio of 10:1 produced best results in terms of maximum nitrogen and carbon removal from the wastewater. The SBR system showed promising results and could be used as a viable treatment alternative in the shrimp industry.

Keywords: Sequencing batch reactor; Shrimp wastewater; Nitrification; Denitrification; C:N ratio

1. Introduction

Inland aquaculture of marine organisms requires a combination of biological and mechanical filtration methods to maintain optimal water quality. Filter systems are backwashed on a regular basis to maintain their effectiveness, which results in the accumulation of sludge and the loss of water. One option to reclaim water is to allow the backwashed wastewater to settle in a container, and then decant the water back into the culture system. However, the anaerobic nature of a settling tank prevents the aerobic nitrification of ammonia (Boopathy et al., 2005). By transferring water from a simple settling tank, excess nitrogen may be added to the culture system.

Sequencing batch reactor (SBR) incorporates alternating aerobic and anaerobic periods to achieve nitrification and denitrification in a single container (Fig. 1). Time is needed at the end of the sequence to allow the sludge to settle so that surface water can be decanted. SBR treatment of eight days (two days aerobic, three days anaerobic, two days aerobic, one day to settle) has been shown to significantly reduce nitrogen and carbon levels in wastewater collected from a high salinity (28 parts per thousand (ppt)) intensive shrimp aquaculture raceway (Boopathy et al., 2005). However, aquaculture systems are operated under different salinity and temperature levels depending on the specific operation. Salinity and temperature levels have a definite impact on the microbial community structure in the wastewater and may affect the nitrification and denitrification process (Colt and Tomasso, 2001) and ultimately the performance of the SBR.

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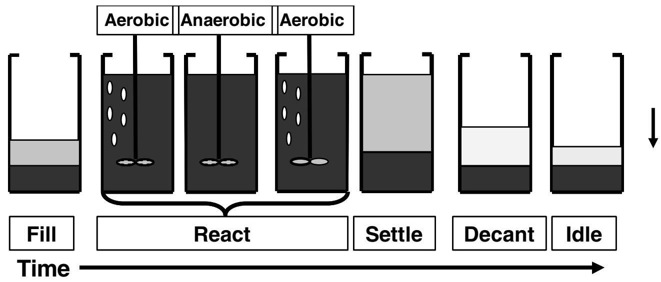

Fig. 1. SBR setup.

The carbon and nitrogen composition of wastewater from shrimp aquaculture operations depends largely on the feed used. Microbial degradation of any wastes depends on the amount of carbon, nitrogen, and phosphorus available for their activity. If there is too little nitrogen present, the bacteria will be unable to produce necessary enzymes to utilize the carbon. If there is too much nitrogen, particularly in the form of ammonia, it can inhibit the growth of the bacteria. The treatment of various wastewaters have been studied by many workers and a common agreement is the carbon to nitrogen (C:N) ratio of 20:1 and 30:1 support most of the useful microorganisms (DeRenzo, 1977; Sathianathan, 1975; Boopathy and Mariappan, 1984).

To improve wastewater management in recirculating aquaculture systems, we studied the effects of salinity, temperature, and C:N ratios on a sequencing batch reactor for the treatment of wastewater from an intensive shrimp aquaculture system. The objective of this study was to determine optimal parameters for SBR treatment of shrimp aquaculture wastewater, so that treated water can be safely returned to the culture system.

2. Methods

Sludge from an intensive shrimp raceway system was collected from bead filter backwash at the Waddel Mariculture Center, South Carolina. The sludge was pooled together and collected in a storage tank. Sludge samples were maintained at 4 °C until the start of the experiment. Trials were conducted by placing 500 mL of wastewater in a 1 L glass flask fitted with an airstone (SBR) and kept at room temperature (approximately 22 °C) unless otherwise stated. The SBR sequence was: aerobic two days, anaerobic three days, aerobic two days, and settle one day, for a total treatment time of 8 days. Thirty mL of sludge was removed from each reactor ($N = 4$) at the beginning of the trial and at the end of each day, centrifuged at 5000 rpm for 10 min, and the supernatant was used for chemical analysis. Total ammonia-N (mg/L), nitrite-N (mg/L), and nitrate-N (mg/L) were analyzed by colorimetric methods with a Hach water analysis kit (Hach, 1999). Chemical oxygen demand (COD) was analyzed using standard methods (APHA, 1998). Dissolved oxygen concentration, salinity, and temperature were measured using a YSI dissolved oxygen and salinity probe (Model no. 85-10FT, Yellow Springs, OH). Data were subjected to analysis of variance (alpha = 0.05) followed by a Tukey's *post hoc* test.

To determine the effect of different salinity and temperature levels on SBR performance, we manipulated either salinity or temperature of wastewater collected from a high salinity culture system. Salinity was decreased by dilution with deionized water or increased by the addition of sodium chloride, resulting in four salinity treatments of 5, 15, 28, and 40 ppt. Temperature was thermostatically controlled by placing the SBR in a heated water bath, resulting in four temperature treatments of 22, 28, 37, and 45 °C. Both experiments were conducted in triplicates. Nitrogen and carbon levels were then compared among salinity treatments and temperature treatments.

To determine the effect of C:N ratio on SBR performance, we manipulated the C:N ratio of wastewater collected from a high salinity culture system. Four C:N ratios of either 10:1, 20:1, 30:1, or 40:1 were created by either adding molasses or ammonium salts. The normal C:N ratio of the wastewater was 5:1. This experiment was conducted in triplicate with triplicate SBRs. Nitrogen and carbon levels were then compared among various C:N treatments.

3. Results and discussion

The shrimp wastewater contained high concentrations of ammonia, nitrate, nitrite, and carbon (Table 1). The salinity variation experiment showed that significant reduction of nitrite-N, total ammonia-N, nitrite-N, nitrate-N, and COD levels in 28 and 40 parts per thousand (ppt)

Table 1
Mean (±SD) initial concentration (mg/L), final concentration, and percent reduction of nitrate-N, nitrite-N, total ammonia-N, and chemical oxygen demand (COD) of sludge from a shrimp culture facility treated with a sequencing batch reactor at different salinities (ppt)

Variable	Salinity	Initial concentration	Final concentration	% Reduction
Nitrate-N	5	173 ± 13	75 ± 8^{A}	57
	15	173 ± 13	28 ± 6^{B}	85
	28	173 ± 13	0 ± 0^{C}	100
	40	173 ± 13	1 ± 1^{C}	99
Nitrite-N	5	98 ± 16	84 ± 25^{A}	14
	15	98 ± 16	51 ± 6^{A}	48
	28	98 ± 16	10 ± 6^{B}	90
	40	98 ± 16	14 ± 9^{B}	86
Total ammonia-N	5	90 ± 5	8 ± 3^{A}	91
	15	90 ± 5	4 ± 3^{AB}	96
	28	90 ± 5	1 ± 0^{B}	99
	40	90 ± 5	0 ± 0^{B}	100
COD	5	1321 ± 106	148 ± 27^{A}	89
	15	1321 ± 106	104 ± 18^{B}	92
	28	1321 ± 106	30 ± 4^{C}	98
	40	1321 ± 106	28 ± 7^{C}	98

Final concentrations within variable groups that share a common letter are not significantly different (alpha = 0.05).

treatments. The low salinity (5 ppt) treatment did not remove significant concentrations of carbon and nitrogen from the shrimp wastewater. The original salinity in the wastewater was 28 ppt and this treatment removed the highest percentage of carbon and nitrogen from the wastewater (Table 1). The microbes present in the wastewater were acclimatized to the salinity and lowering the salinity of the system affected the performance of SBR.

The effect of various temperature on the SBR performance showed that the SBR operated well in the temperature of 22, 28, and 37 °C. However, at the elevated temperature of 45 °C, the removal efficiency of carbon and nitrogen dropped significantly (Table 2). The shrimp aquaculture from where the wastewater was obtained was operated at 28 °C and the microorganisms in the wastewater seem to be adapted to the temperature range of 22–37 °C. There is no need to raise the temperature in order to improve the SBR performance. The wide temperature range of 22–37 °C worked well and removed $> 89\%$ of all nitrogen species and carbon.

It appears that salinity and temperature levels of the shrimp culture system seem to be the optimal conditions to operate the SBR. Because the microbial community changes with salinity and temperature, the efficiency of a biofilter's nitrogen and carbon reduction can be affected by a change in salinity or temperature (Rosenthal and Otte, 1979). Although this study did not monitor the microbial community, it is apparent that the microbial community was affected by a sudden change in temperature and salinity. If given a sufficient amount of time for the microbial community to acclimate to a new salinity or temperature regime (Rosenthal and Otte, 1979), then the efficiency of carbon and nitrogen removal with SBR treatment may have increased at the extreme salinity and temperature levels.

Table 2
Mean (±SD) initial concentration (mg/L), final concentration, and percent reduction of nitrate-N, nitrite-N, total ammonia-N, and chemical oxygen demand (COD) of sludge from a shrimp culture facility treated with a sequencing batch reactor at different temperatures (°C)

Variable	Temperature	Initial concentration	Final concentration	% Reduction
Nitrate-N	22	173 ± 13	0 ± 0^{B}	100
	28	173 ± 13	0 ± 0^{B}	100
	37	173 ± 13	0 ± 0^{B}	100
	45	173 ± 13	70 ± 13^{A}	60
Nitrite-N	22	98 ± 16	10 ± 6^{B}	90
	28	98 ± 16	20 ± 1^{B}	80
	37	98 ± 16	11 ± 8^{B}	89
	45	98 ± 16	94 ± 7^{A}	4
Total ammonia-N	22	90 ± 5	1 ± 0^{B}	99
	28	90 ± 5	0 ± 1^{B}	99
	37	90 ± 5	0 ± 1^{B}	99
	45	90 ± 5	8 ± 2^{A}	91
COD	22	1321 ± 106	30 ± 4^{B}	98
	28	1321 ± 106	30 ± 23^{B}	98
	37	1321 ± 106	26 ± 15^{B}	98
	45	1321 ± 106	211 ± 91^{A}	84

Final concentrations within variable groups that share a common letter are not significantly different (alpha = 0.05).

Table 3
Mean (±SD) initial concentration (mg/L), final concentration, and percent reduction of nitrate-N, nitrite-N, and total ammonia-N of sludge from a shrimp culture facility treated with a sequencing batch reactor for different C:N ratios

Variable	C:N Ratio	Initial concentration	Final concentration	% Reduction
Nitrate-N	5:1	128 ± 3	43 ± 4^{C}	66
	10:1	128 ± 3	1 ± 1^{D}	99
	20:1	128 ± 3	66 ± 14^{B}	48
	30:1	128 ± 3	91 ± 6^{A}	29
Nitrite-N	5:1	105 ± 49	64 ± 3^{B}	39
	10:1	105 ± 49	9 ± 15^{C}	91
	20:1	105 ± 49	56 ± 8^{B}	47
	30:1	105 ± 49	105 ± 6^{A}	0
Total ammonia-N	5:1	69 ± 3	0 ± 1^{B}	100
	10:1	69 ± 3	0 ± 1^{B}	100
	20:1	69 ± 3	11 ± 3^{A}	84
	30:1	69 ± 3	13 ± 5^{A}	81

Final concentrations within variable groups that share a common letter are not significantly different (alpha = 0.05).

The 10:1 C:N treatment had lower final concentrations of nitrate-N and nitrite-N than all other C:N treatments (Table 3). The 5:1 and 10:1 C:N treatments reduced total ammonia-N more than the 20:1 and 30:1 C:N treatments by the end of the eight day sequence (Table 3). All variables tested were reduced by at least 91% for the 10:1 C:N ratio treatment (Table 3). This result showed that the C:N ratio of 10:1 is better than higher C:N ratios. By simply doubling the C:N ratio from 5:1 to 10:1 via the addition of an inexpensive molasses the performance of SBR could be improved significantly.

Previous literature suggests that a C:N ratio of 20:1 or 30:1 is better than a 10:1 ratio for various wastewater treatment such as poultry waste, cow manure, and coffee waste (DeRenzo, 1977; Sathianathan, 1975; Boopathy and Mariappan, 1984). However, we found that a 10:1 C:N ratio was the optimal ratio for SBR treatment of shrimp aquaculture wastewater. The C:N ratio can be manipulated by the feed offered to the culture animals or at a later stage before the wastewater is treated. Based in this study, we suggest that SBR be operated at the salinity and temperature levels of the culture system and that the C:N ratio is maintained near 10:1 for the most efficient treatment of wastewater. This study was conducted at the benchtop scale with only a single batch per reactor. Future work will investigate pilot scale SBR.

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