SIMULTANEOUS REMOVALS OF NUTRIENT AND ORGANIC MATTER IN LIQUID SWINE MANURE USING A LAB-SCALE SEQUENCING BATCH REACTOR

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ABSTRACT

Simultaneous biological nitrogen and phosphorus removals from liquid swine manure with high organic matter were investigated in a lab-scale, anaerobic-aerobic-anoxic-aerobic sequencing batch reactor ($(AO)_2$SBR). The SBR was operated on 3 cycles per day with 8 hours per cycle at constant 20^{o}C. The sludge retention time (SRT) and hydraulic retention time (HRT) were maintained at 15 and 3 days. The biological process removed ammonium and nitrite nitrogen by 99.9 and 99.2%, respectively; however, the removal of nitrate nitrogen was not successful due possibly to insufficient time for denitrification, even when carbon was readily available. The biological removal of phosphorus by phosphorus-accumulating organisms reached 89%, but the effluent still contained phosphorus at a concentration of 5 mg P/L. The $(AO)_2$SBR showed a stable organic matter removal with removal efficiencies of COD and BOD_5 around 97.4 and 100%, respectively. A good reduction in total solids (77.5%), total volatile solids (97.0%), total suspended solids (99.9%), and total volatile suspended solids (99.1%) was also observed.

KEYWORDS. Liquid swine manure, Nutrient removal, Sequence batch reactors, Organic materials

INTRODUCTION

Increasing concern over environment pollution as a result of fast growing animal industry that produces large quantities of manure outstripping the receiving capacity of cropland has led to development of new and complex wastewater treatment processes. One of the most promising processes is the controlled activated sludge process achieved within a device called “the sequencing batch reactor (SBR)” (Kazmi and Furumal, 2000). In the past two decades, research on using SBR to treat liquid animal manure has made tremendous progress, evidenced by the improvement in operating strategy and design in that the removal of carbonaceous biochemical oxygen demand (BOD) and nutrients can be simultaneously accomplished in a single SBR (Bortone et al., 1992; Kuba et al., 1993; Tilche et al., 1999; Lee et al., 2001; Obaja et al., 2003). Meanwhile, reports on using the SBR technology to treat other wastewater streams for nutrients and toxic materials removal can also be found in literature (Keller et al., 1997; Thayalakumaran et al., 2003; Ong et al., 2003; Sarfaraz et al., 2004).

An SBR is usually operated on repetitive cycles, each containing four phases, i.e., FILL, REACTION, SETTLING, and DRAWING, during which nutrients such as nitrogen and phosphorus are removed through biological activities. For instance, during the FILL phase (normally accompanied by gently mixing), denitrification and phosphorus release occur, while phosphorus uptake, carbonaceous BOD removal, and nitrification take place in the subsequent

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aerobic REACTION phase. During SETTLING, nitrate is then removed by endogenous denitrification. For each cycle, the condition in the SBR can be alternated between anaerobic and aerobic for at least once, or several times, to enhance nutrients removal. It is not uncommon to experience poor denitrification in the cycle due to lack of sufficient carbon in the liquid that results from the preceding nitrification process, so an external carbon source may need to be added to the reactor for proper denitrification (Ra et al., 2000).

In this study, a lab-scale, $(AO)_2$ SBR is developed and evaluated for treating swine wastewater aiming at removing nutrients and organic materials. Unlike previous research, this SBR employs two alternating anaerobic/oxic phases to enhance nitrification and phosphorus removal. At the same time, sodium acetate is used as the external carbon source to promote denitrification in the latter part of each cycle. Other than nitrogen and phosphorus removal, discussions are also presented on changes resulted from the treatment in total solids (TS), total volatile solids (TVS), total suspended solids (TSS), total volatile suspended solids (TVSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD).

MATERIALS AND METHODS

Manure Source

Raw manure was collected from a reception sump of a finishing barn at the University of Minnesota Southern Research and Outreach Center, where fresh manure in a shallow pit inside the barn was flushed out biweekly. The collected manure first underwent solids-liquid separation to remove coarse materials (particle size greater than 2.5 mm) and then was stored (usually less than one week) at 4°C if not used immediately. Finally, the manure was diluted with deionized water to around 1.0% TS, which was used to fill the influent tank for the sequencing batch reactor (SBR). The properties of the influent manure were shown in Table 1.

Table 1. Basic properties of the influent manure fed into the SBR

Parameters	*Levels of the constituents*
pH	7.45
TS (%)	1.053
TVS (%)	0.540
TSS (%)	0.766
TVSS (%)	0.442
TKN (mg N/L)	1217
NH_4^+-N (mg N/L)	866.6
NO_3^--N (mg N/L)	0.0
NO_2^--N (mg N/L)	0.0
TP (mg P/L)	600.7
DP (mg P/L)	39.9
COD (mg/L)	8800
BOD (mg/L)	3660
Turbidity (FTU)	2175
DO (mg O_2/L)	0.0
COD:TN:TP	16:2:1
BOD:NH_4^+-N:DP	113:22:1

SBR Configuration

A transparent PVC column, 19.0 cm in diameter, was used to construct the lab-scale SBR having a total volume of 11.0 L with a working volume of 8.0 L. The system consisted of the reactor body, three peristaltic pumps (MasterFlex L/S 7550-30) controlling feeding and discharging of both liquid and sludge, probes (Campbell CSIM11 and Campbell 21X) to monitor oxidation-reduction potential (ORP), pH, and temperature, timers (Coleparmer BH-94460-45), an air pump (Barnant 60010-2392) for aeration, five separated gas-diffusing stones (Fisherbrand), and a computer that performed overall operation and data acquisition through the software (the Linkable Instrument Network for Windows: WIN LIN V1.2) provided by the vendor of peristaltic pumps. A diagram of the whole system was presented in Figure 1.

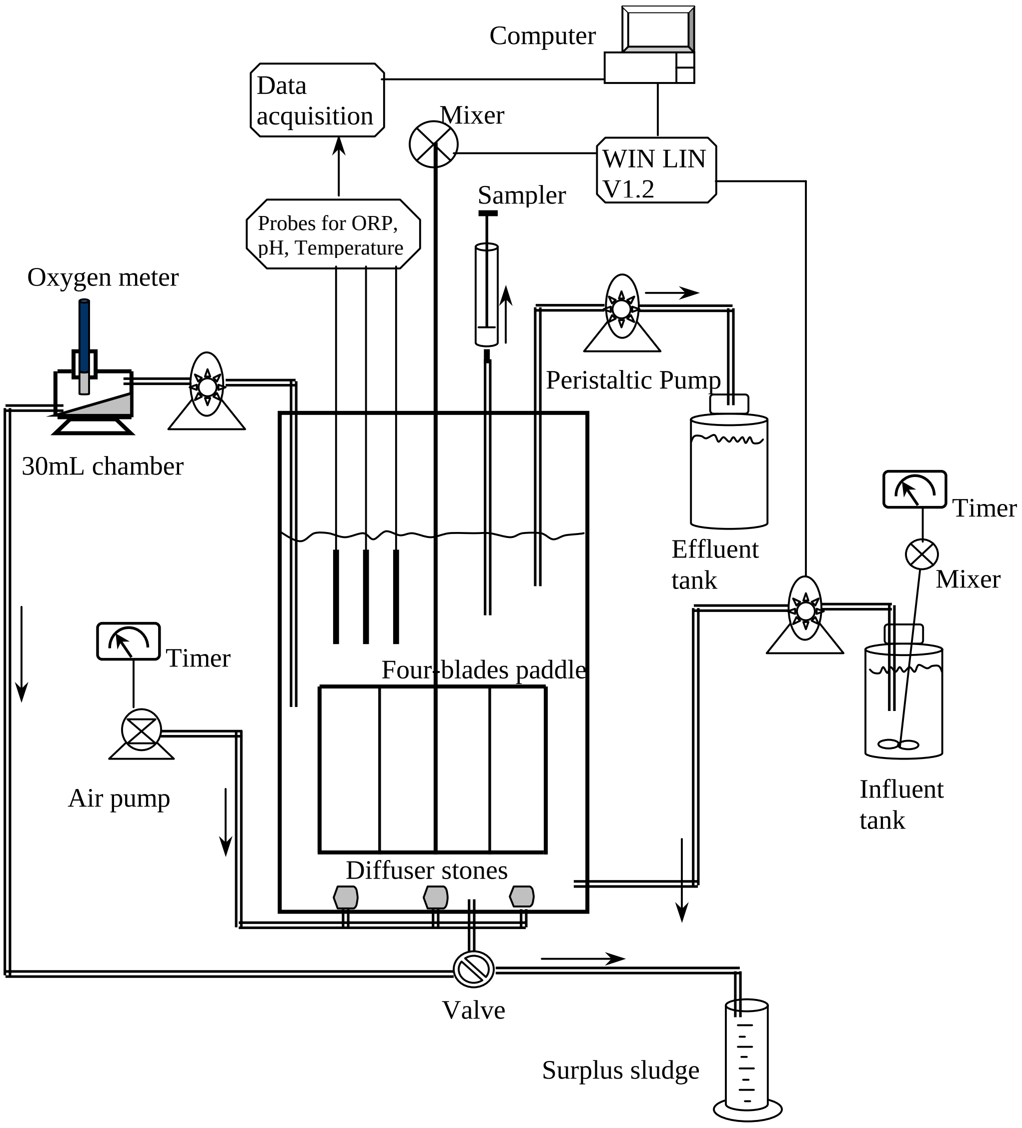

Figure 1. A schematic of the experimental setup for the SBR treatment system

SBR Operation

Activated sludge obtained from the Waseca Advanced Municipal Wastewater Treatment Plant was used as inoculum for startup. After inoculation, the SBR was put in continuous operation for over 3 months at 20 ± 1°C to reach a steady state before the start of the test. In this study, the steady state was defined as occurring when the variation of effluent BOD was less than 5% in a one-week period. A detailed operating time frame for one cycle, as well as the actions and reactions involved, was shown in Figure 2. Each operating cycle consisted of four phases, i.e., FILL, REACT, SETTLE, and DRAW, and lasted for eight hours, resulting in three cycles per day. The SBR was fed twice during each cycle, one at the beginning (600 mL) and the other four hours into the operation (200 mL). The first feeding used the liquid manure in the influent tank, while the second a mixture of manure and sodium acetate solution (concentration: 6000 mg/L COD) at 1:1

ratio to increase carbon source in the liquid for denitrification and phosphorus removal enhancement. At the end of each cycle, supernatant of 800 mL was removed from the SBR, leading to a hydraulic retention time of 3.3 days.

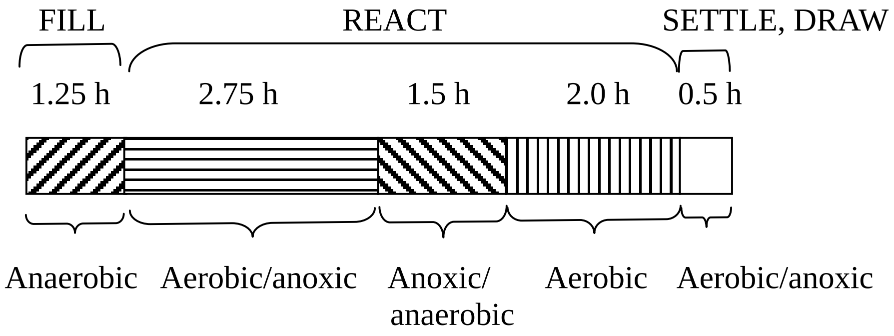

Figure 2. A typical operating cycle for the SBR in the study

The total solids level (biomass plus inorganic minerals) in the SBR was controlled at 1.0% by discharging excess sludge at an amount of 200 mL from the reactor twice a day. The sludge normally had varying total solids levels from 1.85% to 2.52%. The loss in volume due to sludge removal was replenished with water immediately. Based on this operating regime, the solids retention time was calculated to be around 20.8 days. The aeration rate for the study was fixed at 1.5 L air/m^3 manure/s and the agitation speed during feeding and aeration was controlled at 25 rpm using a custom-built, four-blade paddle mixer (15.2 cm wide and 12.0 cm high).

Sample Analysis

Liquid sampling was conducted on 30-min intervals during the cycle and all samples were analyzed for pH, total solids (TS), total volatile solids (TVS), total suspended solids (TSS), total volatile suspended solids (TVSS), total phosphorus (TP), dissolvable phosphorus (DP) and 5-day biochemical oxygen demand (BOD_5), according to the standard methods (APHA, 1998). Total Kjeldahl nitrogen (TKN) was measured using a Foss Kjeldahl Analyzer following digestion. Ammonium nitrogen (NH_4^+-N), nitrite nitrogen (NO_2^--N), nitrate nitrogen (NO_3^--N), chemical oxygen demand (COD), and turbidity were measured using a DR/3000 spectrophotometer (Hach, 1993). Dissolvable oxygen was measured in the liquid circulating through a 30mL chamber outside the reactor using an oxygen meter (Extech, Model 407510). Concentration of total nitrogen was determined as the sum of TKN, NO_2¯N, and NO_3^--N.

RESULTS AND DISCUSSIONS

Nitrogen

The changes in ammonium, nitrite, and nitrate nitrogen during the 8-h operating cycle are presented in Figure 3. In the FILL phase, since anaerobic environment in the SBR dominated, the nitrate left from the previous cycle was completely converted to nitrogen gas (although not measured) at the end of the phase through denitrification. In the meantime, the level of ammonium nitrogen (NH_4-N) increased rapidly to about 100 mg N/L due to fresh manure addition in absence of oxidative environment necessary for the nitrification process to occur. In the subsequent REACTION phase, the environment in the SBR was alternated between aerobic and anaerobic to assist nitrogen removal. In the first aerobic stage, NO_3^--N increased from zero to 15 mg N/L, accompanied by a slight increase of NO_2^--N (from zero to 2.5 mg N/L) and a moderate decrease of NH_4-N (from around 87 to 63 mg N/L). Mass balance calculation revealed that not all the NH_4-N was converted into NO_2^--N or NO_3^--N and the difference (about 6.5 mg N/L) could be the loss due to ammonia emission, which was not monitored in this study. Following the aerobic stage, the

NO_3^--N and NO_2^--N concentrations continued to increase about halfway into the anaerobic stage before starting to decrease as a result of the start of denitrification. At the end of the anaerobic stage, most of the NO_3^--N and NO_2^--N produced during the aerobic period was denitrified to nitrogen gas that escaped from the liquid. The whole pattern repeated in the second aerobic stage but at a lower level (Figure 3). Addition of a mixture of manure and sodium acetate (200 mL) at the fourth hour of operation somewhat kept the NH_4-N level in the anaerobic stage virtually unchanged, which provided a nitrogen source for nitrification in the subsequent aerobic stage, as reflected by the abrupt increase in NO_3^--N. At the end of the second aerobic stage, almost all NH_4-N from both feedings was removed (99.9%). However, denitrification of NO_3^--N was barely achieved, resulting in about 15 mg N/L of NO_3^--N left in the liquid. Failure to carry out denitrification could be a result of two factors, i.e., lack of a carbon source and insufficient reaction time. Since sodium acetate, as a carbon source, was added in the second feeding, the possibility of deficiency in carbon in the liquid could thus be ruled out. Therefore, it may be inferred that the poor denitrification in the SETTLE/DRAW phase is largely due to insufficient time allocated to that phase (only 30 minutes).

Dissolved Phosphorus

Figure 4 presents the changes of phosphorus in the treated liquid. In the FILL phase, the anaerobic environment forced bacteria to use energy – adenosine tri-phosphate (ATP) – to obtain readily biodegradable organic carbon substrates and store them as polyhydroxyalkanoates (PHAs), with the release of phosphorus into the liquid, which was indicated by the increase in dissolved phosphorus (DP) concentration in the liquid. In the subsequent aerobic phase, the same group of bacteria (called phosphorus accumulating microorganisms) used PHAs to generate energy for growth, glycogen synthesis, and phosphate uptake, which led to decrease in DP in the liquid (Figure 4). Although fresh manure was added to the reactor at the fourth hour, the change of DP was marginal, and so was the reduction of DP in the rest of operating phases. At the end, the DP level in the liquid returned to the starting level which was around 5 mg P/L and the reactor was ready for the next run.

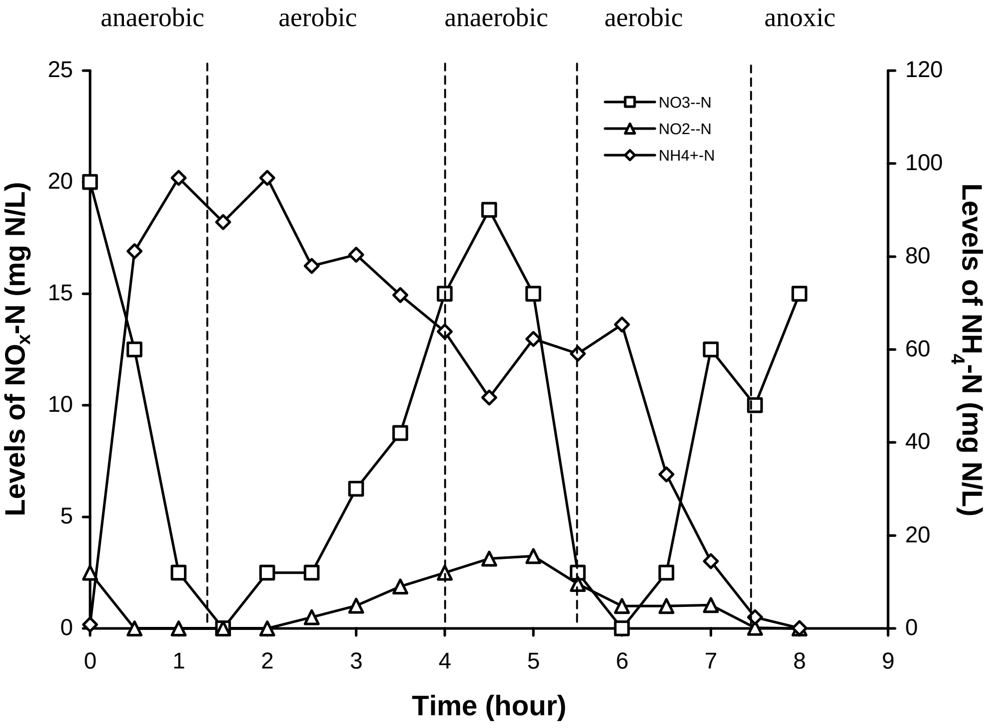

Figure 3. Changes in NH_4^+-N, NO_3^--N, and NO_2^--N concentrations during the 8-h cycle

Changes of All Other Parameters Measured in This Study

Table 2 presents information, based on analysis of influent and effluent samples, on total solids (TS), total volatile solids (TVS), total suspended solids (TSS), total volatile suspended solids (TVSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD). The data showed that the $(AO)_2$SBR system could reduce TS, TVS, TSS, and TVSS by 77.5, 97, 99.9, and 99.1%, respectively. The reductions in COD and BOD were also significant (97.4 and 100%), evincing that the system could produce quality effluent that would less likely pose a threat to the environment. The final effluent was a clear, odorless, and yellowish liquid with a reduction in turbidity by 94.5%.

Table 2. Chemical and biochemical properties of the influent and effluent

Parameters	Influent	Effluent	Reduction (%)
TS (%)	1.053	0.237	77.5
TVS (%)	0.540	0.016	97.0
TSS (%)	0.766	0.001	99.9
TVSS (%)	0.442	0.004	99.1
COD (mg/L)	8800	226	97.4
BOD (mg/L)	3660	0	100
Turbidity (FTU)	2175	120	94.5

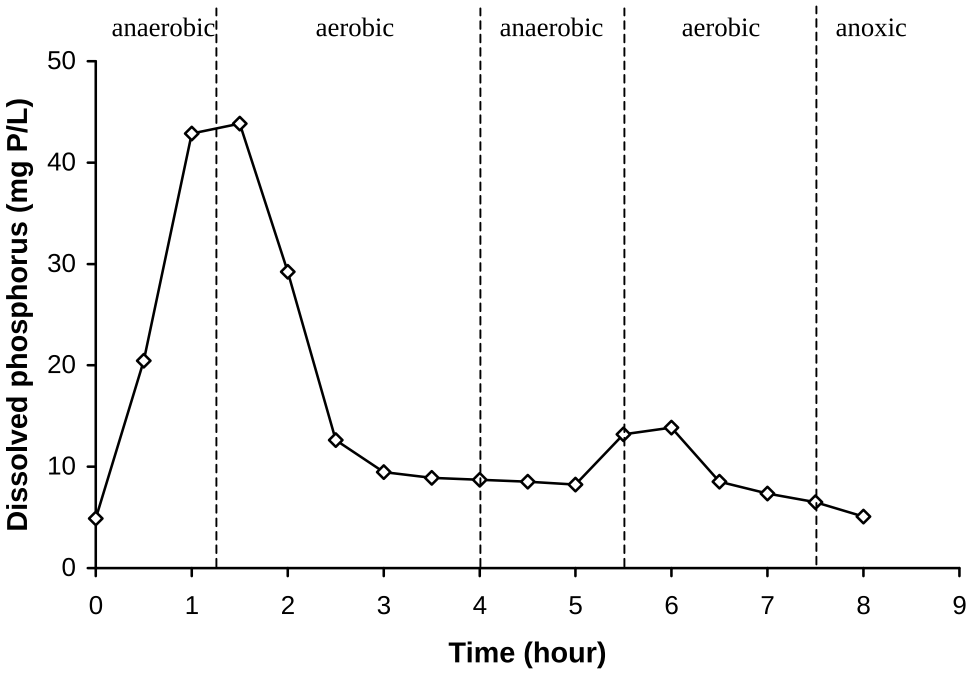

Figure 4. The changes in dissolved phosphorus during a full cycle of SBR operation

CONCLUSIONS

1. The $(AO)_2$ SBR system successfully carried out the nitrification process which led to a nearly complete removal of ammonium nitrogen added to the reactor in both feedings (99.9%). Also removed was nitrite nitrogen at the end of the cycle, although it was not present at a significant level throughout the treatment. However, the system failed to perform proper denitrification, leaving a level of about 15 mg N/L in the effluent, due possibly to insufficient time allocated to the SETTLE phase. Therefore, it may be

concluded that even with sufficient carbon in the liquid, the SBR may not be able to produce the expected treatment results without an appropriate design for system operation.

2. The system was able to reduce the dissolved phosphorus (DP) level in the liquid by about 89% with the effluent containing 5 mg P/L. This value is not low enough to meet the limit for effluent discharge to surface waters, which is 1 mg P/L. More work is needed to improve the SBR operation to further reduce the phosphorus content in the effluent.
3. The system achieved removal of TS, TVS, TSS, and TVSS in the treated liquid by 77.5, 97.0, 99.9, and 99.1%, respectively. Significant reductions in BOD and COD were also observed (100 and 97.4%). At this level of reduction, it is anticipated that the effluent from the SBR treatment will not cause odor problems if stored for land application.

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