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Feasibility Study of Sequencing Batch Biofilm Reactor for the Treatment of Domestic Wastewater

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Abstract
The present study is that the application of Sequencing Batch Biofilm Reactor (SBBR) for treating the domestic wastewater. The SBBR utilized in this study contained biomass immobilized in inert support material (polyurethane foam cubes) also as suspended biomass. The SBBR took 26 days to succeed in the steady state condition with treated wastewater Chemical Oxygen Demand (COD), phosphorus, ammonia-nitrogen and nitrate-nitrogen concentrations of 14 mg/l, 3.6 mg/l, 4.5 mg/l and 6.1 mg/l respectively. The SBBR was operated for 106 days and through the study nearly complete COD removal was observed and therefore the effluent phosphorus concentration was within the range of 2.7 to 3.6 mg/l, ammonia-nitrogen concentration was less than 1 mg/l and denitrification were nearly 100% at the end of anaerobic phase.

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I. Introduction

Biological methods are used successfully at municipal and industrial levels to get rid of these nutrients. In this regard choosing the efficient treatment system is important. Sequencing Batch Reactor (SBR) may be a modification of activated sludge process which has been successfully wont to treat municipal and industrial wastewater. The conventional activated sludge process for nutrient removal is space-oriented system. However, SBR is a time-oriented system which typically includes the following steps: fill, react, settle, decant and idle phases. SBR has been employed has an efficient technology for wastewater treatment, especially for domestic wastewaters, because of its simple configuration and high efficiency in COD and suspended solids removal (USEPA, 1993). The SBR may be a fill and draw activated sludge system for wastewater treatment. Equalization, aeration, and clarification can all be achieved employing a single batch reactor. They are uniquely suited for wastewater treatment applications characterized by low intermittent flow conditions (Hue et al., 2005). In recent years application of SBR to biofilm reactors was suggested by Morgenroth and Wilderer (1999) to overcome the difficulties about the growth and maintenance of suspended activated sludge flocs, this combined system is called a Sequencing Batch Biofilm Reactor (SBBR). SBBR is considered to be the hybrid of fully developed SBR technology and one of the newer applications of sequencing batch reactor treatment technology to treat domestic wastewater for the removal of organic matter, nitrogen and phosphorus simultaneously. SBBR's have a potential advantage compared to suspended growth process because of less sludge and compact reactor design. SBBR operation is same as SBR except for the support media used.

Biofilms bear a greater potential for the simultaneous and efficient removal of organic carbon and nutrients like N and P in wastewater treatment. They are spatially heterogeneous, providing space for both, aerobic and anaerobic processes; they're compatible for nitrification, since attached growth of the slow-growing nitrifying bacteria protects them from washout; and they can be exposed to alternating anaerobic and aerobic conditions as necessary for enhanced biological phosphorus removal (EBPR). In this study the performance evaluation of SBBR was made with regard to removal of organic carbon, nitrogen and phosphorus from synthetic wastewater.

Sequencing Batch Biofilm Reactor

The Sequencing Batch Biofilm Reactor (SBBR) is a relatively new application of sequencing batch treatment technology benefited from advantages of both biofilm systems and periodic processes. The attached suspended growth SBR, a kind of SBBR, is a process coupling suspended activated sludge and attached growth processes into a single system (Hu et al., 2005). In an attached growth treatment process, a biofilm consisting of microorganisms, particulate matter and extra cellular polymers is attached and covers the supporting material, which may be plastic, rock or other material. Substrate is consumed within a biofilm, substrates, oxygen and nutrients diffuse across the stagnant liquid layer to the biofilm, and products of biodegradation from the biofilm enter the bulk liquid after diffusion across the stagnant film (Metcalf and Eddy, 2003).

It has been reported by researchers that attached growth systems are more effective for nitrification and denitrification. The SBBR mode of operation could enhance nitrate removal which in turn is beneficial for phosphorus removal (Hu et al., 2005 and Pedros et al., 2007). Helness and Odegaard (2001) stated that there is a potential advantage compared to ASP in biofilm processes for biological nutrient removal. In more compact biofilm processes there will be less vulnerability with respect to sludge loss and the solids retention time is governed by sloughing of biomass. According to Morgenroth and Wilderer (1998) the only sink of phosphorus in the SBBR is the removal of phosphorus rich biomass through backwashing once a day at the end of aerobic period.

Compared to the conventional nitrification and denitrification processes the oxygen demand is 50 % lower in the nitrification step and less COD is consumed in the subsequent denitrification step since nitrite is used as the terminal electron acceptor in the SBBR method, This is because nitrite bacteria became dominant and nitrite accumulated gradually and during the subsequent anoxic stage along with the concentration debasement of the dissolved oxygen, Ammonia Oxidation (ANAMMOX) bacteria became dominant; then, the nitrite that was accumulated in the aeration stage was wiped off with ammonium simultaneously (Zhengyong et al., 2007). One of the interesting aspects with regard to SBBR is that the acidity produced between aeration and anoxic periods by the nitrite bacteria was neutralized in time by the alkalinity produced by the ANAMMOX bacteria during the anaerobic period.

Hu et al., (2005) in their work has used both attached and suspended growth SBR systems to compare and investigate the performance characteristics of nitrogen and phosphorus removal from municipal sewage. They have used three controlling factors, namely batch loading rate, feed pattern and mixing/aeration ratio under nine experimental conditions, but though it was very difficult to show all the available combinations experimentally, they have developed a cost effective Taguchi method for designing of all experiments and to obtain the optimal operating condition to facilitate simultaneous removal of nitrogen and phosphorus. The performance comparison of both attached and suspended growth systems under all experimental conditions in terms of COD, BOD5, suspended solids, nitrogen and phosphorus were done and have observed that both attached and suspended growth SBR systems have shown the importance of phosphorus uptake rate to the phosphorus removal performances and the simultaneous removal of nitrogen and phosphorus, but suspended system showed good phosphorus removal efficiency, while attached was slightly better in nitrogen removal.

Kumar and Chaudhari (2003) evaluated the performance of SBR and SBBR for simultaneous nitrogen and phosphorus removal from synthetic wastewater containing glucose as carbon source. They operated three reactors SBR-1 containing only suspended biomass, SBBR-2 and SBBR3 containing 5 % and 10 % polyurethane foam media respectively along with suspended biomass and observed that in all reactors phosphorus removal was nearly same and was more than 80 % and greater than 90 % nitrification was achieved. In their studies they also identified that ORP and pH can be useful for real time control and optimization of the process.

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II. Materials And Methods

Reactor System and Feed

The experiments were carried out in a 3 L working volume laboratory scale SBR and SBBR. SBBR initially was operated as conventional SBR which was later converted to SBBR after 5 days by adding 10 % of the liquid volume of the SBR with Porous Biomass Carrier (PBC) media. The PBC used was polyurethane foam of size 1 cm × 1 cm × 1 cm. Both the reactors were inoculated with cow dung slurry as seed culture and were aerated for several days to obtain a dense culture to start with. Later the following phases were provided for both the reactors: fill, anaerobic phase, aerobic phase, settle and decant. At the end of each cycle, the mixed liquor suspended solids were allowed to settle for 30 min and 50 % of treated wastewater was removed for analysis. Aeration was provided by using aquarium pump connected to diffuser stones. Synthetic wastewater used throughout the study provided a source of carbon, nitrogen; phosphorus and trace elements required for biomass growth. It had the following composition: glucose, 400 mg/l; ammonium chloride, 125 mg/l; di-potassium hydrogen orthophosphate, 70.3 mg/l; magnesium sulphate, 50 mg/l; manganese sulphate, 5 mg/l; sodium hydrogen bi-carbonate, 10 mg/l; calcium chloride, 3.75 mg/l.

Operational Strategy of SBBR

The entire study was carried out using batch reactor using cow dung as seed cultures. Initially the system was operated as conventional SBR which was later converted to SBBR after 5 days. This was done by adding 10 % of the total liquid volume of the SBR with porous biomass carrier (PBC) media. The PBC used was polyurethane foam (PUF) of size 1 cm × 1 cm. × 1cm. The total number of PUF to be added was calculated as follows:

10% of the total volume = 0.1 x 3 L
= 0.1 x 3/1000 m^3
= (0.3/1000) x 10^6 cm^3
= 300 cm^3

SBBR was operated for one cycle per day with the following predetermined operational strategy: fill, anaerobic, aerobic, settle, and decant phases. The operational condition of SBBR is given in Table 1. In the fill stage synthetic wastewater was added to the SBBR to mix the biomass held in the tank. During the react phase the biomass consumes the substrate under controlled conditions: anaerobic, aerobic, and in settle phase mixing and aeration were stopped and the biomass was allowed to separate from the liquid resulting in a clarified supernatant. 50 % of treated effluent was removed from the SBBR at the end of each cycle followed by addition of fresh synthetic wastewater of same quantity. Finally in draw phase supernatant were removed for analysis.

Table 1 Operational strategy for SBBR

Volume, L	3
Hydraulic retention time, h	48
Number of Cycles per day	1
Duration of anaerobic-react phase, h	17
Duration of aerobic-react phase, h	6
Duration of settle, decant and fill phase, h	1

Plate 1 Laboratory scale sequencing batch reactor/ sequencing batch biofilm reactor (settle phase)

SBBR was operated for one cycle per day with the following predetermined operational strategy: fill, anaerobic, aerobic, settle and decant phases. In the fill stage, synthetic wastewater was added to the SBBR to mix the biomass held in the tank. During the react phase the biomass consumes the substrate under controlled conditions: anaerobic, aerobic, and in settle phase the biomass was allowed to separate from the liquid resulting in a clarified supernatant. Cow-dung was used as seed material and 50 % of treated effluent was removed from the SBBR at the end of each cycle followed by addition of fresh synthetic wastewater of same quantity. Samples of the influent, end of anaerobic phase and effluent of SBBR were collected two to three times per week for routine monitoring (Asha,(2008).

Before analysis samples were filtered through 0.45 µm filter paper to measure all dissolved chemical parameters. Immediate analysis of samples was carried out as soon as possible. Collected samples which could not be analyzed were kept in the sample preservator at 4 ºC. The samples were analyzed for chemical oxygen demand (COD), ammonia-nitrogen, nitrite nitrogen, nitrate nitrogen and phosphorus in accordance with standard methods (APHA., 2005). The pH measurements were carried out by using pH analyzer. Biomass concentrations (total suspended solids and volatile suspended solids) were determined by filtering the samples through 0.45 µm filter paper and drying it in a hot air oven at 103 ºC for 24 hours and volatile solids were analyzed by vaporizing the samples at 550 ºC in muffle furnace for half an hour (Metcalf and Eddy, 2003).

III. Results And Discussion

PERFORMANCE OF SBBR

The performance of SBR is typically comparable to the conventional SBR system. The SBBR system was seeded initially with 250 ml of fresh cow dung sieved through 2mm standard sieve, further it was diluted to 1000 ml with the tap water and was fed with synthetic wastewater. This was an attached cum suspended SBR system. Wherein microorganisms responsible for the conversion of the organic material or nutrients were found attached to the porous biomass carriers. Air circulation for the void space was given by diffusers, providing oxygen for the microorganisms growing as an attached film.

The SBBR was operated with one cycle per day giving sequence of cycle which includes: anaerobic phase (17h), aerobic phase (6h), settle, decant and fill phases (1h). In SBBR, simultaneous nitrification and denitrification was achieved with a thick biomass. The compounds present in the bulk liquid outside the biofilm penetrate the film by diffusion, which leaves the possibility of different conditions and bacterial populations in different depths. Zhan et.al, (2006) in his study has reported that oxygen diffused completely into the bottom layer of biofilms with thickness less than 300 µm, and the oxygen penetration depth increased with increasing biofilm thickness. As a consequence, microbial distribution changes with the biofilm thickness due to the competition for substrate and space in biofilms. In an aerobic biofilm, heterotroph and nitrifiers dominate in the top layer. Therefore, thin biofilms with thickness of 300-400 µm are appropriate for simultaneous oxidation and nitrification.

Figure 1(a) shows the variations of COD and phosphorus for the entire study period. The influent concentration of COD and phosphorus maintained was 400mg/L and 12.5 mg/L respectively. On the day 1, the COD uptake in the anaerobic phase was 54.57% and corresponding phosphorus release observed was 32.11%. Comparing to the rate of COD uptake in the conventional SBR, in SBBR since the substrate is consumed within the biofilm, the rate of COD uptake was high, and this is because

SBBR had another portion of biomass provided by the attached growth. On the day 30 the concentration of COD at the end of anaerobic phase was 29 mg/L and corresponding phosphorus release was 17.4 mg/L (46.45 %) and in the subsequent aerobic phase the concentration of COD was 22 mg/L and phosphorus uptake was 5.9 mg/L. The effluent concentration of the phosphorus was 3.5 mg/L (65.52 %).

Figure 1(b) shows the variations of ammonia nitrogen and nitrate nitrogen at the end of anaerobic and aerobic phases. On day 1, ammonia oxidation was 83 % indicating that the ammonia oxidizing bacteria became dominant, the nitrite and nitrate that was accumulated in the aerobic phase was oxidized easily.

As reported by Zhengyong et.al, (2007) the nitrite bacteria became dominant and nitrite accumulated gradually. During the anoxic stage, along with the concentration debasement of the dissolved oxygen, ammonia oxidizing (ANAMMOX) bacteria became dominant, and then the nitrite that was accumulated in the aeration stage was wiped off with ammonium simultaneously. It can be observed from the figure that nitrification was observed from the day 23, onwards and at the end of the study period it was range of 90-100 % with the effluent ammonia nitrogen concentration less than 1 mg/L.

In all cases, the ammonia oxidation rate did not change significantly indicating that the activities of ammonia oxidizers were not influenced significantly by free ammonia or nitrite. The activity of denitrifying microorganisms was also not affected by the nitrite that accumulated as all the nitrite and nitrate produced in the aerobic period were completely removed in the second anoxic period Jie et.al, (2007) and Rhee et.al, (1997).

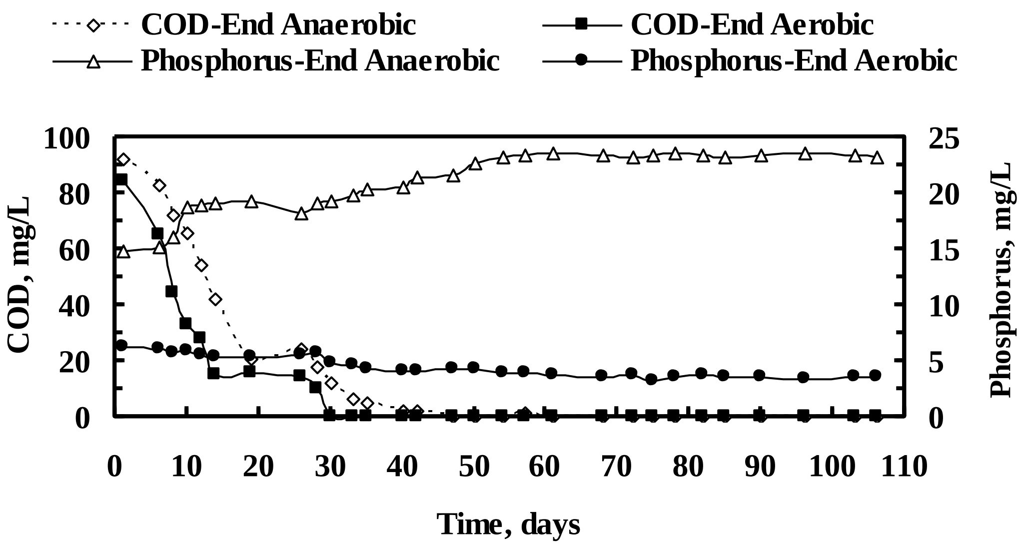

Figure 1(a) Profiles of COD and phosphorus removal in SBBR

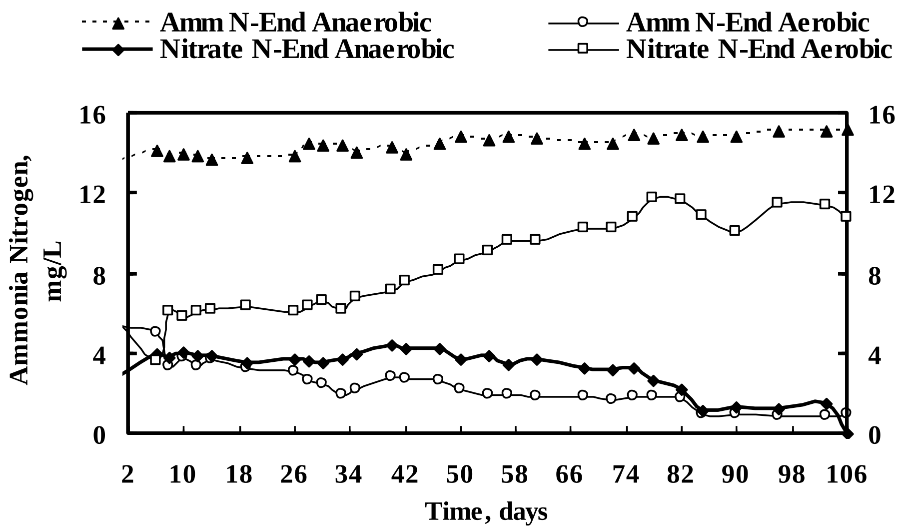

Figure 1(b) Profiles of ammonia nitrogen and nitrate nitrogen, phosphorus removal in SBBR

TRACK STUDY IN A CYCLE OF SBBR

As the regulations of effluent quality are increasingly stringent and influent loads is, the on-line monitoring of wastewater processes become very important to meet ever increasing effluent quality. Several points are identified to adjust the duration of anaerobic and aerobic phases in a cycle of SBBR. Those points correspond to the biological changes occurring in the system. The pH probe was immersed in the SBBR for continuous monitoring and the pH value was recorded whenever sample was drawn. Samples were collected for every 15 minutes for first one hour and subsequently every half an hour for both the phases.

Figure 2(a), (b) and (c) shows the COD, pH, and ammonia nitrogen profiles with respect to time in a cycle both in anaerobic and aerobic phase. The change in pH values during a cycle of a biological system responds to microbial reactions and hence, the pH variation often provides a good indication of ongoing biological reactions. Different critical points can be detected in the pH curve.

As reported by Zhengyong et.al, (2007) pH plays a very important role in the process of bacterial cultivation and domestication and the feasible growth range of pH for the ANAMMOX bacteria was 6.7-8.3 and the highest reactivity velocity appeared at the pH of about 8.0. In the study, researchers have also said that pH in SBBR was always between 7.3 and 7.8 without addition of alkalinity or acidity which created a condition with feasible pH for ANAMMOX bacteria.

At the beginning of the cycle, there was a rapid pH reduction (point 1, 2 on Figure 4.15) signifying increase in phosphorus release rate and the similar trend was observed until first 2.5 and was slow during next 0.5 h, the rate increased remarkably after 0.5h indicating anaerobic phase. Then onwards pH increases due to denitrification indicating the point as "nitrate knee" (point 1, 2 and 3 on Figure 4.15), the rate of pH decrease was observed to be slower once the phosphorus release process ceased owing to nitrification. There was a change in slope of pH, maximum phosphorus release (P_r on Figure 2(a)) can be observed in complete anaerobic conditions. This change in the slope of pH can be used to terminate the anaerobic phase.

Nitrification was observed when there is a reduction in pH (0.5 h to 2 h). As a result the required aeration time for nitrification was shorter. The pH started increasing probably due to expelled carbon di oxide by air stripping and phosphate uptake (point P_u on Figure 2(a). The reduction in the alkalinity by prevailing nitrification decreases the pH until it reached a minimum. This minimum in the pH profile is called "ammonia valley" and correspond to the end of nitrification. After the ammonia valley, the pH increases due to the stripping of carbon di oxide. Thereafter the pH reaches to an inflection point before decreasing slightly. This peak is "nitrate apex" which corresponds to complete denitrification.

Phosphorus concentration decreased rapidly during the aeration phase. The COD reduction started immediately at the onset of the beginning of the cycle, and was further reduced at the end of anaerobic phase since in the attached growth process organic substrate is consumed within the biofilm.

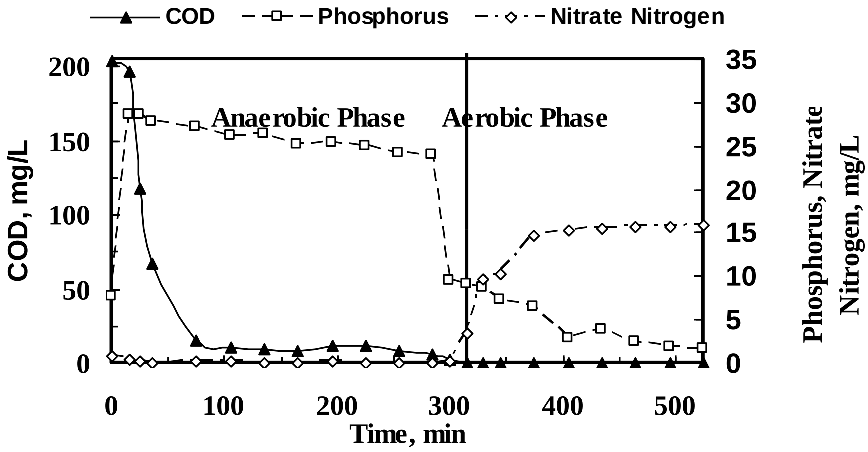

Figure 2(a) Variations of COD, nitrate nitrogen and phosphorus in a cycle of SBBR

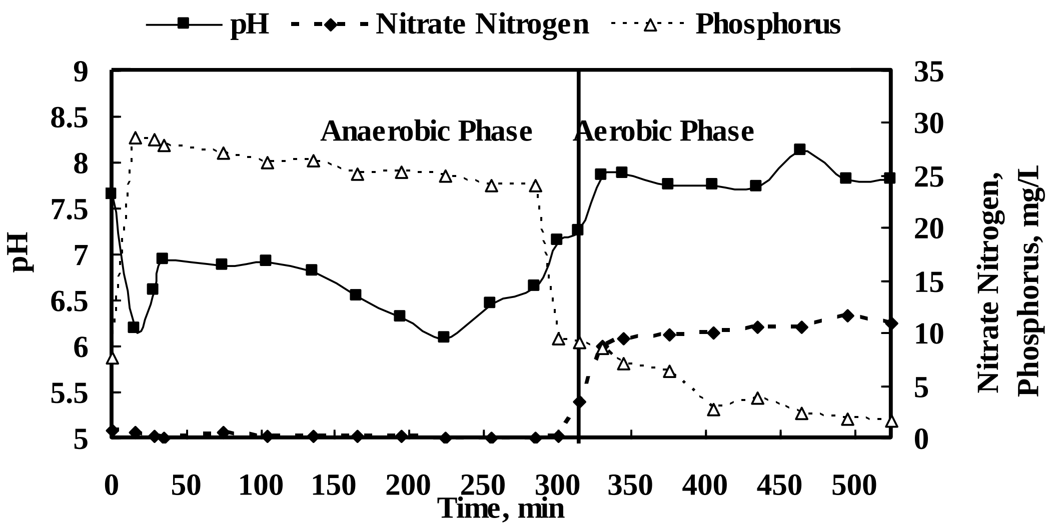

Figure 2(b) Variations of pH, nitrate nitrogen and phosphorus in a cycle of SBBR

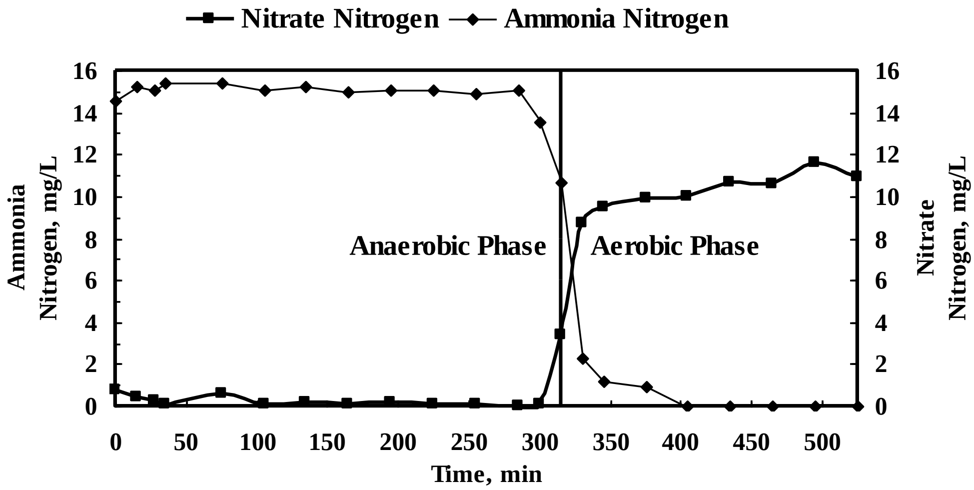

Figure 2(c) Variations of ammonia nitrogen, and nitrate nitrogen in a cycle of SBBR.

IV. Conclusions

This study investigated the performance of SBBR system for treating synthetic domestic wastewater. From the study following conclusions were obtained:

-The organic carbon removal, nitrification and denitrification rate was high in SBBR.

-The treated effluent from the reactor contained COD, ammonia nitrogen and phosphorus within the prescribed limits for the discharge of wastewater standards.

-SBBR showed stable performance from day 26 onwards, the COD uptake and phosphorus release observed was 99 % and 65 % respectively with effluent concentration less than 4 mg/l and 3.5 mg/l.

-Complete denitrification was observed and the effluent ammonia nitrogen concentration was less than 1 mg/l.

-SBBR had the edge with respect to nitrate nitrogen reduction.

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