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Effect of lag-phase in the transition from oxic to anoxic conditions on the performance of the sequencing batch reactor

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ABSTRACT: Sequencing batch reactors (SBRs) are usually preferred as small and decentralized wastewater treatment systems. Using a frequent enough switching between oxic and anoxic conditions, it is possible to bypass the second step of nitrification (i.e. conversion of nitrite to nitrate nitrogen) in SBR. The effect of oxic/anoxic ratio (R) on nutrient removal from municipal wastewater was examined in 5 m^3 pilot-scale SBR operated at ambient temperature. During the react phase, the reactor was intermittently aerated specific aeration intervals. DO, pH and oxidation–reduction potential (ORP) in the reactors were real-time monitored. It was found that partial nitrification followed by denitrification successfully occurred in the intermittently aerated SBR system with R =3/6 (30 min oxic/60 min anoxic). Results showed aeration ratios, above R > (1/6), do not have a significant effect on COD and TSS removal efficiency.

KEYWORDS: Sequencing Batch Reactor, Oxic/Anoxic, Nutrient Removal.

1 INTRODUCTION

Intermittently aerated reactors have been successfully used for nitrogen removal from wastewater by achieving partial nitrification denitrification (PND) technology for combined carbon and nitrogen removal ().Intermittently aerated reactors can potentially be optimized if used to perform partial nitrification followed by denitrification via nitrite, resulting in reduced oxygen demand for ammonia removal and reduced organic substrate for denitrification. We hypothesized that aeration cycles with sufficiently short aerated periods or sufficiently long nonaerated periods can provide appropriate conditions for partial nitrification and denitrification via nitrite. This process is based on the facts that, since nitrite and nitrate are intermediary compounds in nitrification and denitrification, a partial nitrification to nitrite and denitrification from accumulated nitrite, instead from nitrate, would be feasible to remove high concentrations of nitrogen compounds in the wastewaters [1-4]. In contrast to the traditional biological nitrogen removal (BNR) process, PND has the following advantages [5-6]: Lower oxygen consumption by 25% in the aerobic phase implies 60% energy saving in the entire process, the requirement for electron donors is as much as 40% lower in the anoxic phase, NO_2denitrification rate is 1.5 to 2 times higher than NO_3denitrification rate and reduction of the generated sludge by up to 75%. The inhibition of nitrite-oxidizing bacteria (NOB) is critical for PND because NOB oxidizes NO_2^- to NO_3^- and converts partial nitrification to complete nitrification [7]. Several parameters, including DO concentration [8], temperature, pH [9], SRT [10], substrate concentration, ratio of carbon to nitrogen (C/N) [11], aeration pattern, and chemical inhibitor,...etc. have been found to selectively inhibit NOB. Intermittent aeration favors partial nitrification [12]. a SBR system was operating with a “react” phase divided into three sets of consecutive aerobic and anoxic periods with a duration ratio of 1:3, the nitrogen removal was achieved via nitrite. This was attributed to the suppression of the nitrite-oxidizers activity due to the short aerobic phase duration [13]. PND was successfully completed using the aeration control strategy, even though the temperature decreased from 32 °C to 21°C [14]. Reference [15] showed that the aeration per cycle, taking advantage of the lag-time of nitrite-oxidizers behind ammoniaoxidizers was important parameters for effective PND in the proposed SBR. The removal efficiency of N and P was improved when anoxic reaction time as long as possible when allocating anoxic/aerobic reaction time within a cycle, and also the first and last reactions of cycle in SBR should be anoxic and aerobic, respectively. Each anoxic or aerobic time in a cycle should be over 30 minutes for high removal of nitrogen and phosphorus, but the repetition frequencies of alternate anoxic/aerobic state may be insignificant in removal efficiency [16]. Reference [17] studied the operation of SBR under three different variations of aerobic-anoxic sequence, viz. 4:4, 5:3 and 3:5 hours. It has been observed that 85 to 92% of soluble COD removal would be possible at the end of 8.0 hour of overall reaction period, irrespective of the length of the aerobic react period. In the case of 4:4 hour operating cycle, reasonable degree of nitrification (88-100%) and denitrification (73-75%), along with 91-94% of organic carbon removal have been achieved, which has been considered to be the optimum performance of the reactor. In this study, different lag phases were adopted to treat a real wastewater in order to reduce the final COD and nitrogen concentration. The ratio of aerobic/anoxic for each cycle was different.

2 MATERIALS AND METHODS

2.1 THE SEQUENCING BATCH REACTOR

The experiment set-up was located in the laboratory of water and wastewater laboratory (Elminia, Egypt). The pilot-scale SBR (Figure 1) was composed cylindrical plastic tank with holding capacity of 5m^3 made of high density polyethylene, electrical control panel for distributing power supply and controlling the operation of pumps and the implementation of SBR phases for the treatment of influent sewage. Two electric pumps for the suction of raw sewage equipped with a highly reliable grinder system, two centrifugal pumps for the recirculation of mixed liquor and aeration through the use of a venturi aspiration device, two centrifugal pumps for the decanting of treated effluent from the SBR reactor to the chlorination tank and two similar pumps for the disposal of chlorinated effluent to the final receptor. The SBR was operated in a fill and draw mode following a predefined and repeated cycle.

During all reaction phases, a mixing device (centrifugal pump) kept the reactor contents under homogenous conditions at all times and achieves aerobic conditions. Treated wastewater was discharged from the reactor until a predefined minimum reactor water level was reached. The reactor was equipped with a floating-probes system for on-line monitoring of pH (mod.1200-S sc LANGE), ORP (1200-S sc LANGE), temperature (PT-100), DO (LDO sc LANGE) , Sc 1000 probe module for connecting up to4 sc sensors and SC 1000 display module with GSM for remote data interrogation and remote operation.

Figure 1: photo of the SBR pilot plant.

The SBR was operated by means of an in-house developed data acquisition and control software program developed by Laboratory of Biochemical Engineering and Environmental Technology, Patras University, Greece (LBEET). The software was able to repeat over time a previously defined cycle operation by controlling the switching on/off of aeration, the centrifugal pumps, the mixing device, and the air supply. The monitoring module was able to acquire on-line sensors presenting them in a graphical interface.

2.2 ANALYTICAL METHODS

A wide range of techniques was employed to address the research objectives defined in this study. It includes reactor process studies, chemical oxygen demand (COD), Ammonium (N-NH_4), Nitrite (NO_2), Nitrate (NO_3), Phosphate (PO_4), total suspended solids (TSS), volatile suspended solids (VSS), The combination of these multi-disciplinary techniques has helped deliver significant outcomes. mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were analyzed according to the analytical methods 2540D and 2450E of Standard Methods (APHA 1998). Total and soluble chemical oxygen demand was analyzed by adapting the analytical method ISO 6060-1989, DIN 38409-H41-H44. Ammonium ($N-NH_4$) was analyzed by adapting the analytical method $4500-NH_3$.B-C of Standard. For ammonium determination, the sample was distilled. The ammonia in the distillate has been determined by Ion Chromatography (ICS 1100). Phosphate was analyzed by adapting method 4110B of Standard Methods APHA (1998) described in nitrates and nitrites determination (3.3.9II).

2.3 CHEMICALS

The chemicals used in IC measurement were supplied by fisher scientific UK limited, reagent (LCK 514) used for analysis of COD were supplied by HACH Lange GMBH, Germany.

3 RESULTS AND DISCUSSION

In order to study the effect of lag-phase in the transition from oxic to anoxic conditions on organic materials removal in SBR, 24 hours cycles with different oxic/anoxic periods were studied. Definitions of the cycles studied in this study are shown in Table (1).

TABLE 1. OPERATION CONDITIONS FOR THE CYCLES THAT WERE STUDIED

Cycle No.	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
Oxic period (min)	0	10	20	30	60
Anoxic period (min)	60	60	60	60	60
Total COD (mg/l)	471	841	1263	1418	1168
Ammonia (mg/l)	11.9	17.4	29	6.4	17.5
Nitrite (mg/l)	0.11	3.7	0.01	0.01	0.01
TSS(mg/l)	1200	2120	2110	1418	2350
pH	7.5	7.29	7.78	7.68	7.82
Temp. (°C)	24	30.8	29.5	29.4	31.9

The DO value began to increase in all sets with the beginning of aeration (aerobic phase) in the reactor. It was observed that the DO value reached 2.0 to 2.5 mg/L. At the start of anoxic react period most of the cases, DO was found to be less than 1 mg/L and at the end of anoxic react period the value becomes less than 0.5 mg/L. The results (Fig. 2) show that 80 and 53 % of COD and TSS was removed at the end of the cycle 1 on the other hand, the concentration of ammonium in the end of the cycle was slightly increased, as shown in Fig. 3, this may be attributed to prolonged anoxic time periods. During the low dissolved oxygen (average DO level of less than 1.0 mg/L), incomplete nitrification will occur, which will lead to a build-up of ammonium within the SBR due to the insufficient aeration time to convert the ammonia to nitrate.

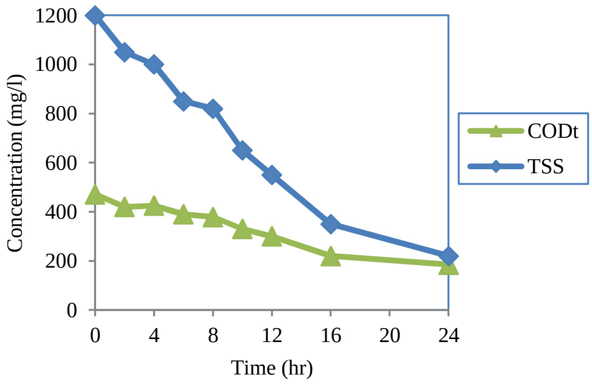

Fig. 2. Profile of COD_t and TSS during cycle (1).

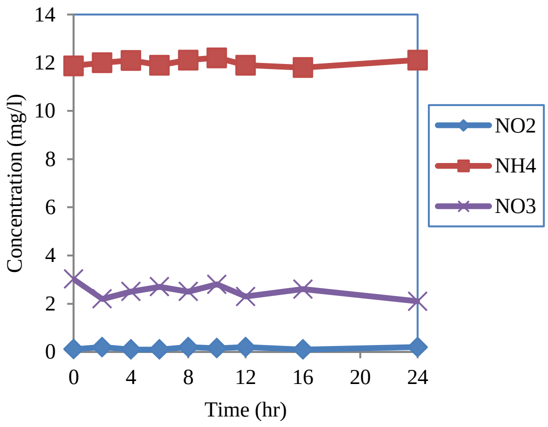

Fig. 3. Profile of ammonium, nitrite and nitrate during cycle (1).

During cycle 2 the biological nitrogen removal was achieved via nitrites (by-passing nitrates). Ammonium nitrogen was removed at the end of the cycle (93.8 %), the concentration of nitrates and nitrites in the end of the cycle was 3.5 and 0.0 (Fig. 4). The results in Fig. (5) show that 82 and 92 % removal efficiency of COD and TSS respectively was obtained.

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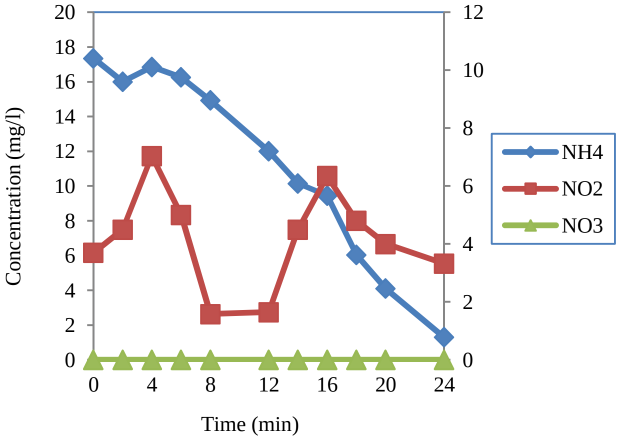

Fig. 4. Profile of ammonium, nitrite and nitrate during cycle (2)

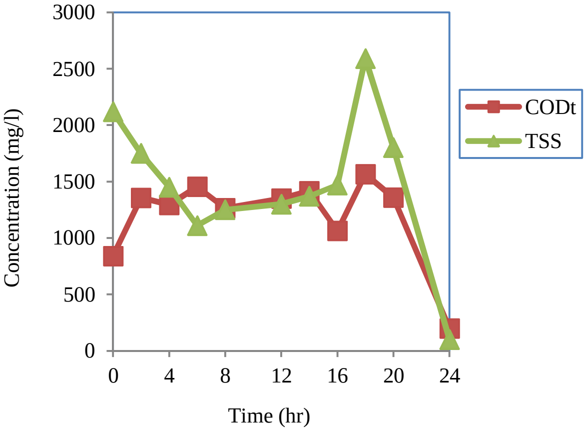

Fig. 5. Profile of COD_t and TSS during cycle (2).

In cycle 3, as shown in Fig. (6), ammonium was removed by 41 %, indicating low removal efficiency, and this ratio was not enough for nitrification/denitrification. Removal efficiency of COD and TSS was 86 and 98% respectively (Fig. 7).

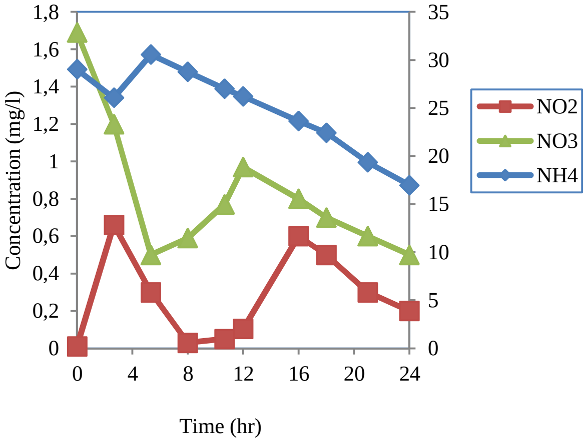

Fig. 6. Profile of ammonium, nitrite, nitrate and phosphate during cycle (3).

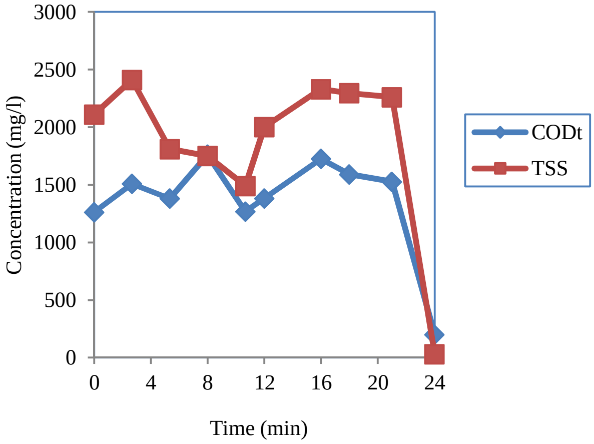

Fig. 7. Profile of COD_t and TSS during cycle (3).

In case of cycle (4) period of 30 min aerobic and 60 min anoxic, it has been observed that at the end of 24 hour cycle period, ammonia oxidation was found to be 100% ; the concentration of nitrates and nitrites in the end of the cycle was 0.94 and 1.7 mg/l, refer to successful PND process. Removal efficiency of COD and TSS in this cycle was 90 and 98% respectively (Fig. 9).

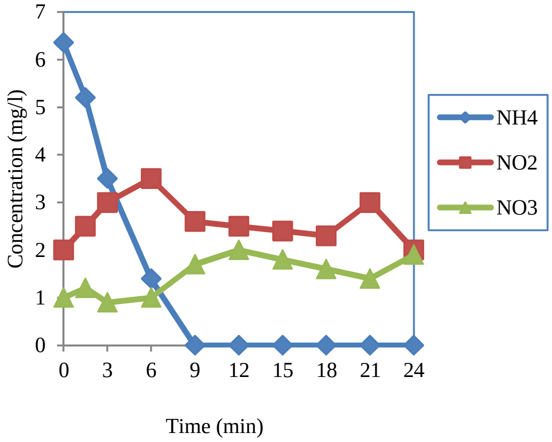

Fig. 8. Profile of ammonium, nitrite, nitrate and phosphate during cycle (4).

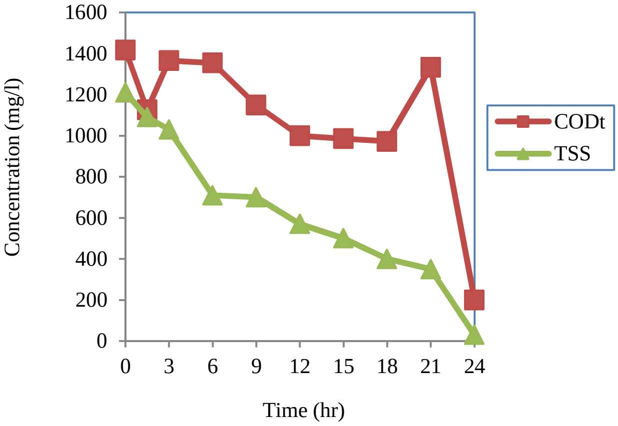

Fig. 9. Profile of COD_t and TSS during cycle (4).

Ammonium nitrogen was 12.75 mg/l at the end of the cycle 5 with removal efficiency 27 % (Fig. 10), while the concentration of nitrates and nitrites in the end of the cycle was 1 and 3 mg/l, indicating low degree of PND. The results in Fig. (11) show that 84 and 98 % removal efficiency of COD and TSS respectively was obtained.

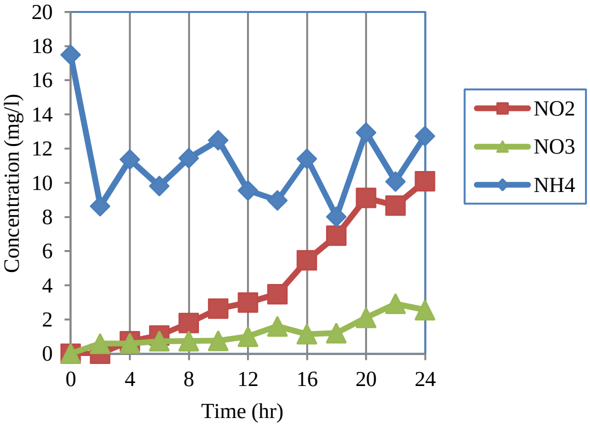

Fig. 10. Profile of ammonium, nitrite, nitrate and phosphate during cycle (5).

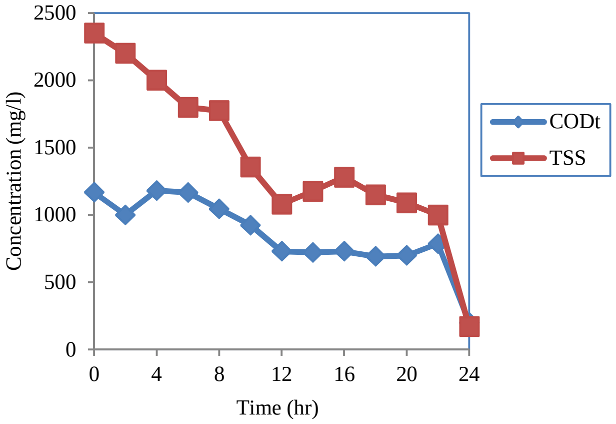

Fig. 11. Profile of COD_t and TSS during cycle (5).

In the present work, the effect of lag phase on COD and nitrogen removal from wastewater was investigated. It is revealed from Figures (2, 5, 7, 9 and 11) that the concentration of COD decreases slightly with an increase in the aeration time from 10-hrs to 60-min, the COD level has decreased rapidly during aerobic react period as compared to its rate of removal during anoxic condition. These results denote that aerobic heterotrophs are prominence in SBR at earlier react period. However, organic carbon requirement during denitrification stage also satisfied. When aeration time increased to 60-min, the removal of COD was increased from 80 to 84% (Fig. 12).

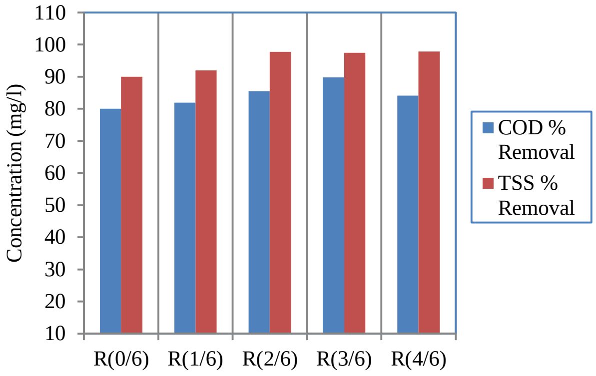

Fig. 12. Summary of the results.

In all cycles, the gradient of ammonium concentration at the beginning and the end of the aeration phase was clearly higher than gradient of nitrate concentration. This means that unbalanced ammonium oxidation-to-nitrate or nitrite and ammonium removal from wastewater in the aeration phase were observed. There was also a variation in N removal efficiency with aeration time. It was observed that N removal is not directly proportional to aeration time, This indicates that total anoxic reaction period should be optimized to improve nitrogen removal,

4 CONCLUSION

Effect of lag-phase in the transition from oxic to anoxic conditions was selected as operational parameter to study the optimization of biological carbon and nitrogen removal from municipal wastewaters. Results showed that changing time of aeration period from 0.0 to 60 min do not have a significant effect on COD and TSS removal efficiencies and just slight difference of COD changes via time (Fig.12). On the other hand, the lag-phase plays an important role in PND process, when the aeration time changed, the ammonia oxidation profile and the PND process varied differently, i.e. the optimum condition was R =3/6 (30 min oxic, 60 min anoxic), where complete removal of ammonium was achieved.

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