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Nitrogen Removal from Wastewater in a Continuous Flow Sequencing Batch Reactor

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Abstract: The purpose of this study was to determine whether continuous flow SBR could provide efficient nitrogen removal in synthetic and domestic wastewater. The experiment was carried out using pilot scale at Tehran University of Medical Sciences; into first stage at laboratory with synthetic wastewater and second stage in treatment plant with domestic wastewater. The results showed that in laboratory and treatment plant 80 and 70% of total nitrogen removal, respectively and 95 and 85% of total kjeldahl nitrogen removal, respectively could be achieved by the system.

Key words: Continuous flow SBR, nitrification, denitrification, nitrogen removal

INTRODUCTION

Biological nitrogen removal from wastewater is an essential treatment to avoid unpleasant conditions for natural receivers. Among the problems occurring in receivers, caused by the various nitrogen forms (ammonium- nitrite and nitrate- nitrogen) are fish toxicity, eutrophication and oxygen depletion[1]. Nitrogen removal consists of ammonium- nitrogen oxidation to nitrite (nitritification) and finally to nitrate (nitratification) and reduction of produced nitrate- nitrogen to gas nitrogen, sequentially via nitrite, nitric oxide and nitrous oxide (denitrification)[2].

In recent year, Sequencing Batch Reactors (SBRs) have great interest for wastewater treatment, because of their simple configuration (all necessary process are taking place time-sequenced in a single basin). SBRs could achieve nutrient removal using alternation of anoxic and aerobic period[3], nitrification and denitrification are achieved in a SBR by mentioned periods, while the separation of treated wastewater and microorganisms is accomplished by ceasing aeration and/or mixing at the end of process cycle[4]. Due to its operational flexibility, it is quite simple to increase its efficiency in treating wastewater by changing the duration of each phase rather than adding or removing tanks in continuous flow systems.

While the conventional SBR system has many advantages, it does have some shortcomings[5].

Removing the motioned disadvantages and to achieve nitrogen removal an experimental study (pilot plant) has been performed. This system is a modification and enhancement of the superior technology of the conventional SBR. The system allows continuous inflow of wastewater to the basin. Influent flow to the basin is not interrupted during the settle and decant phases or at any time during the operating cycle.

In conventional SBRs there are five phases; fill, react, settle, draw and idle[6], but in this system there is only three phases; react, settle and draw. It must be noted again that influent never disrupts in any phase. Continuous inflow allows the process to be controlled on a time, rather than flow basis and ensures equal loading and flow to all basins. Use of a time-based control system facilitates simple changes to the process control program. The duration of each cycle and segment of each operating cycle are the same among all basins in a time-based system. Therefore, changes to the process are made simply by changing the duration of individual segments.

The reactor was separated into two zones (pre-react and main react) by a baffle wall. The pre-react zone acts as a biological selector enhancing the proliferation of the most desirable organisms while limiting the growth of filamentous bacteria, as an equalization tank and as a grease trap[7].

In SBRs, influent is batch and in cases that we want continuous inflow, there must be at least two SBR basins. This increases the cost of construction two basins.

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Additionally the batch inflow causes unequal loading (both hydraulic and organic) during a day in basins, which could affect on biomass. This research was done to remove the mentioned disadvantages of SBRs, especially batch inflow. We wanted to determine weather does system could remove nitrogen while influent in continuous.

The purpose of this research was to determine the system capability in removing nitrogen from wastewater.

MATERIALS AND METHODS

Continuous flow SBR reactor: Experiments were carried out using a lab scale continuous flow SBR reactor with an operating volume of 36 L. The reactor was seeded with sludge from the return line of aerobic basin of Ghoods' Wastewater Treatment Plant. An air pump and diffusers provided sufficient aeration and mixing of the mixed liquor. Temperature at laboratory was maintained at $231°C$, but in treatment plant temperature varied between 10-30°C. Wastewater was introduced into pre-react zone, using a diaphragm dosing pump and flows through openings at the bottom of the baffle wall and into the main react zone where BOD removal and nitrification occur. Effluent was discharged by gravity though a solonid valve. Analog timers controlled the operation of the system. A schematic of pilot is shown in Fig. 1.

Synthetic wastewater: The synthetic wastewater was prepared in a 60 L barrel. The feed contained Glucose as the sole organic carbon source (about 370 mg L^{-1}) and ammonium chloride as nitrogen source (about 48 mg L^{-1}). A combination of potassium hydrogen phosphate (K_2HPO_4) and potassium dihydrogen phosphate (KH_2PO_4) was used both to buffer the mixed liquor in the range of

Table 1: Typical composition of domestic wastewater

Substrate	Concentration (mg L^{-1})
COD	417
BOD	230
TJN	48
TSS	255
TP	16

7.0-7.5 and to provide a phosphorus source for sludge. Sodium hydrogen carbonate ($NaHCO_3$) was added in excess to ensure that the nitrification process was not limited by alkalinity[8].

Domestic wastewater: Typical composition of domestic wastewater used in second stage is shown in Table 1.

Experimental procedures: In general a typical sequencing batch reactor (SBR) includes five distinct phases namely fill, react, settle, draw and idle. In the present work there are only three phases namely react, settle and draw; which in all of these phases wastewater flows to reactor and doesn't disrupt. Firstly the wastewater enters to pre-react zone, with low MLSS concentration to create a high F/M ratio that prevents filamentous growth causing sludge bulking. After a short retention time (15-20 min) wastewater flows to main react zone through openings at the bottom of baffle wall. Distribution of wastewater is accomplished by "Distribution Tubes" that are installed at the bottom of reactor. In react phase air diffusers act air supply and mixing of mixed liquor in aeration basin. In settling phase, a thick sludge blanket is formed. This blanket is enough heavy to prevent disruption settled sludge. Organic constituent are used by microorganisms during passage of wastewater from this layer. In draw phase, clear supernatant in removed through a floating decanter. Figure 2 shows typical phases of this system. All of the decanted effluent is collected and analyzed.
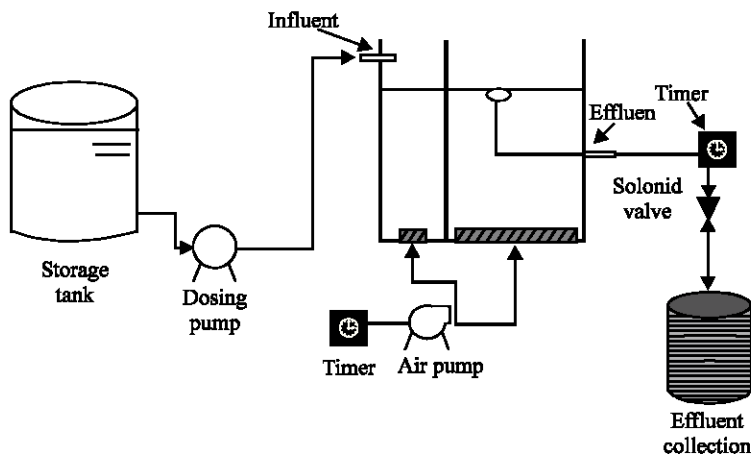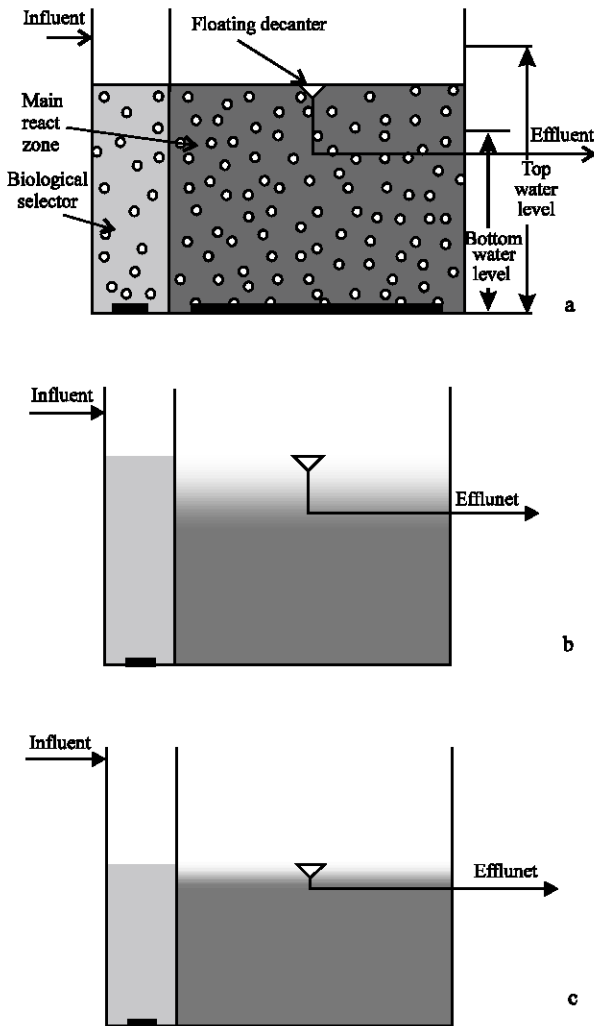

Fig. 1: Schematic of designed pilot

Fig. 2: Different phases of a continuous flow SBR
(a) aeration phase; (b) settle phase and © decant phase

Experiment was done in two stages: First stage in laboratory and with synthetic wastewater and second stage in treatment plant and with domestic wastewater.

In the first stage there were 3 different runs. Run 1: 4 h cycle (Q = 1 L/s, HRT = 20 h); Run 2: 6 h cycle (Q = 1 L/s, HRT = 22 h) and Run 3: 8 h cycle (Q = 1 L/s, HRT = 24.4 h). Also in the second stage there were 3 different runs. Run 4: 6 h cycle (Q = 1.5 L/s, HRT = 16.7 h); Run 2: 6 h cycle (Q = 2 L/s, HRT = 14 h) and Run 3: 6 h cycle (Q = 2.5 L/s, HRT = 12.4 h). First stage was to determine the most efficient run to remove contaminant and second stage was to determine system capability to remove contaminant from domestic wastewater.

It must be noted that in all run 50% of total cycle time was allocated to aeration, 25% to settling and 25% to decanting.

RESULTS AND DISCUSSION

Each of the runs, last one month under mentioned conditions. Average operating conditions and influent and effluent concentration for each run are listed in Table 2. Solids retention time (SRT) ranged from 12.5 to 37 days, hydraulic retention time (HRT) varied form 12.4 to 24.4 h, reactor MLSS ranged from 5906 to 6680 mg L^{-1}, average temperature in laboratory was 231°C and in treatment plant ranged from 10 to 24°C.

The results showed that organic and ammonium nitrogen in terms of total kjeldahl nitrogen (TKN) could be efficiency removed in all runs (over 80%) except off run 6. In run 6, temperature was between 8 to 14°C. Nitrification and denitrification are both temperature dependent[9] so that the activities of nitrifying bacteria are completely stopped at 5°C[8].
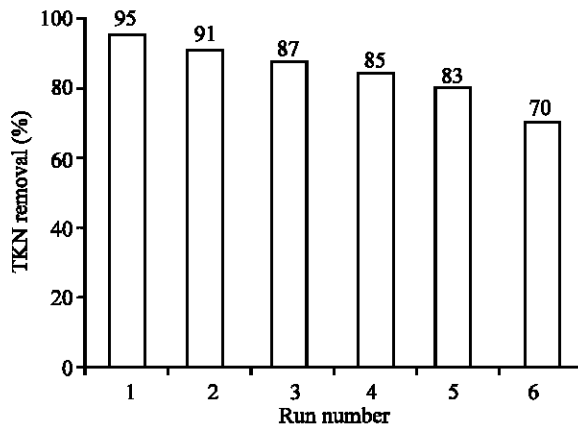

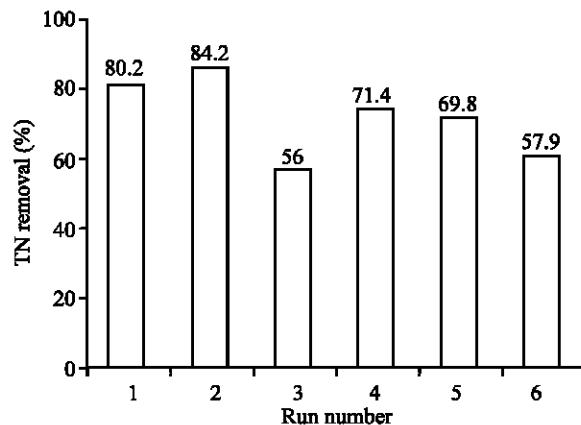Fig. 3: Total kjeldahl nitrogen removal in runs 1 to 6

Fig. 4: Total nitrogen removal in runs 1 to 6

Table 2: Operating conditions and influent and effluent (in parenthesis) concentrations

Test run (reactor)	1	2	3	4	5	6
Cycle time (h)	4.000	5.000	8.000	6.000	6.000	6.000
Aerated fraction	0.500	0.500	0.500	0.500	0.500	0.500
HRT (h)	20.000	22.000	24.400	16.700	14.000	12.400
SRT (day)	37.000	28.000	24.000	24.000	16.000	12.500
F/M	0.111	0.122	0.132	0.107	0.137	0.133
MLSS (mg/L)	6680.000	6337.000	5906.000	6146.000	6002.000	6033.000
MLVSS (mg/L)	5005.000	4694.000	4152.000	3678.000	3480.000	3469.000
Temperature (°C)	23.000	22.000	23.000	20.000	16.000	11.000
COD (mg/L)	371.000 (15.2)	375.000 (7)	373.000 (10.8)	417.000 (21)	417.000 (25)	417.000 (29.2)
BOD$_5$ (mg/L)	342.000 (7.5)	345.000 (3.4)	343.000 (5.4)	230.000 (5.2)	230.000 (6.2)	230.000 (7.3)
TKN (mg/L-N)	44.500 (2.3)	44.900 (4)	46.200 (6)	47.900 (7.1)	47.900 (8.3)	47.900 (14.6)
NO$_3^-$ (mg/L- N)	(6.300)	(5.500)	(11.600)	(6.800)	(6.300)	(5.600)
NO$_2^-$ (mg/L- N)	(0.470)	(0.470)	(0.450)	(0.140)	(0.130)	(0.130)
Total N (mg/L)	45.300 (9.07)	46.000 (9.97)	47.000 (18.5)	48.700 (14.04)	48.700 (14.73)	48.700 (20.33)
Total P (mg/L-P)	16.400 (14.2)	16.200 (14.1)	16.600 (13.8)	16.100 (9.7)	16.100 (7.9)	16.100 (7.3)
pH	7.100	7.600	7.500	7.500	7.300	7.300

The TKN removal in runs no. 1 to 5 was in the range of 83 to 95% (run no. 6 = 69%). Also TN removal was high in all runs (between 70 to 80%) except of runs no. 3 and 6 (about 60%). This indicated that in settle and decant phase dissolved oxygen arrived to zero anoxic conditions becomes predominate, so that denitrification occurs[10]. As a results, nitrite and nitrate levels in effluents were relatively low (below 7 mg L^{-1}) in all runs except of run no 3 (11 mg L^{-1}). This indicated that nitrogen removal at this run is not successful or in the other words denitrification did not occur completely.

Figures 3 and 4 shows system capability in nitrogen removal in different runs.

There is no significant different of TN removal in run no. 1 and run no. 2, but in remove of other contaminants (BOD, COD and TSS) run no. 2 is the best run.

It is demonstrated that high nitrogen removal in continuous flow sequencing batch reactor could be achieved in treating domestic wastewater. Total nitrogen removal as high as 80% in laboratory test and as high as 71% could be obtained from this experiment. The method could be used in small to medium sized communities' wastewater treatment plant. Nitrogen removal is a by product. High MLSS concentration in aeration tank aids to create anoxic conditions as soon as after aeration phase to achieve denitrification for nitrogen removal.

ACKNOWLEDGMENT

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