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EFFECT OF SLUDGE RETENTION TIME ON TREATING HIGH LOAD SYNTHETIC WASTEWATER USING AEROBIC SEQUENCING BATCH REACTORS

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ABSTRACT
The main aim of this study was to investigate the effect of sludge retention time on performance of aerobic synthetic Batch Reactor for treating a high load milk synthetic wastewater. For this purpose, four lab-scale sequencing batch reactors were operated under aerobic conditions with the same conditions at different sludge retention times (SRTs), feeding by high load milk synthetic wastewater. Operating volume, influent flow rate and influent organic loading rate for all reactors were adjusted to 5.5 L, 3.5 L/d and 1400 gCOD/m^3d, respectively. The average effluent COD for reactor 1 to 4 with SRT of 5, 10, 15 and 20 d were 108, 97, 91 and 84 mg/L, respectively. COD removal was 94.99, 95.43, 95.86 and 96.16 percent respectively and slightly changed with SRT. However, the overall trend of COD removal vs. SRT showed an increasing rate with the correlation factor (R^2) of 0.99. Reactor 2 with SRT of 10 d(SVI) had the maximum effluent TSS_{ave} (34mg/L) and $turbidity_{ave}$ (5.89 mg/L) and the minimum sludge volume index (41mL/g). All reactors had SVI_{ave} of lower than 75 mL/g and effluent $turbidity_{ave}$ less than 6 NTU which was lower than Iranian national discharge standards (<50 NTU). SRT had directly influenced the biomass concentration, as the $MLSS_{ave}$ of reactor 1 to 4 were found to be 1824, 2694, 3210 and 3864 mg/L respectively. Best performance (minimum effluent COD, TSS and turbidity) was occurred in reactor 4 with SRT of 20 d.

Keywords: Aerobic Sequencing batch reactor, High load wastewater, Sludge retention time, Organic loading rate.

INTRODUCTION
Batch reactors unlike continuous systems usually work with interrupted or small flowrates. In these reactors, instead of adjusting process levels in a linear manner at different treatment facilities, all processes have to be happened in a unique reactor and they just simply divided by time sequences as it would have more benefit-cost for small amount of wastewater flows. In general, sequencing batch reactor (SBR) includes five steps of fill, react, settle, discharge and idle time. Main advantages of SBR in comparison with other biological processes are treatment flexibility, nutrient removal by nitrification and denitrification, reduction of operation area and low startup cost. SBR as a developed activated sludge process was used for treatment of many types of industrial wastewater such as tannery, fiber, slaughterhouse, dyes, dairy and phenol wastewater (Arrojo *et al.* 2004; Farabegoli *et al.*, 2004; Ganjidoust *et al. 2004*; Vaigan *et al.* 2009, Cassidy *et al.* 2005; Sirianuntapiboon *et al.* 2006b,).

Dairy industries have been developed in recent years in Iran, as more than 2,646,000 tons/yr of pasteurized milk is produced by approximately 223 factories (Statistical Report, 2007). The influent COD of dairy wastewater may vary from

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500 mg/L to 10000 mg/L (Arrojo *et al.* 2004; Sirianuntapiboon *et al.* 2005; Broughton *et al.* 2007). Dairy industries produce wastewater with a high organic Loading Rate (OLR) fluctuation resulting by seasonal products and products variation such as yogurt, ice cream, milk, cheese whey and other relevant products (Healy *et al.*, 2007; Broughton *et al.*, 2007).

It is well known that sludge retention time (SRT) is the one of the main important factors, which can change the state of biomass in an activated sludge system. Several studies regarding the effect of sludge retention time on SBR were reported (Mines *et al*. 1998; Kargi *et al*. 2002; Han *et al*. 2005). Nutrient removal by SBR as a function of sludge retention time was studied for five steps complex anaerobic/oxic/anoxic process (Kargi *et al.* 2002). The effect of SRT on membrane fouling and bioactivities in a membrane unit coupled to a SBR were also reported (Han *et al.* 2005). Furthermore, the bionutrient removal at different SRTs treating a domestic wastewater was studied in three SBRs (Mines *et al.* 1998). In spite of numerous studies for the effect of SRT on SBR performance, a few researches try to report solely the effect of SRT on treatment a high load wastewater. Therefore, the main objective of this study was to investigate the effect of sludge retention time on performance of aerobic SBRs treating a high load milk synthetic wastewater.

MATERIALS AND METHODS

Reactors and operation

Four reactors($R_1$to R_4 in cylindrical shape (Fig 1) with 14 cm diameter and 46 cm height had a total operating volume and wastewater influent flow rate of 5.5 L and 3.5 L/d, respectively. The operating cycle of each reactor consisted of 2 min static filling (Fill), 22.5 hr aeration (Reaction), 1 hr settle down (Settle), 2 min effluent discharge (Discharge), and finally 30 min as idle time (Idle). All the operation parameters like pH, dissolved oxygen (DO), temperature, cycle time and influent organic loading rate (OLR) were the same in all reactors and only the sludge retention times (SRT) were different. Reactors ran for 70 days (including 10 days of acclimatization) and removal efficiencies and sludge characteristics were studied in 60 days of operation.

Synthetic wastewater

The synthetic wastewater was made of powdered milk, urea ($CO(NH_2)_2$) as nitrogen source , potassium hydrogen phosphate (K_2HPO_4) and potassium di-hydrogen phosphate (KH_2PO_4) as phosphorous source. Influent COD and OLR of all SBRs were selected to be about 2200 mg/L and1400 gCOD/m^{3}d, respectively.

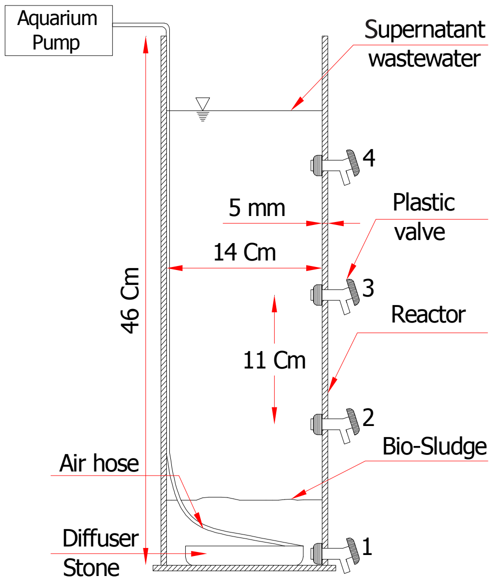

Fig.1: A schematic diagram of sequencing batch reactor

Reactor startup

The reactors were seeded by returned activated sludge of Zargandeh municipal wastewater treatment plant in north of Tehran city. Microorganisms were adapted within 10 days of step feeding by milk synthetic wastewater (MSWW) with no excess sludge removal, till reached the target OLR of 1400 gCOD/m^{3}d. Step feeding was started by 550 mg COD/L of MSWW in first three days and reached the target load within 10 days. Data gathering started after 10th day when all reactors reached the target OLR of 1400 gCOD/m^{3}d (influent COD of 2200 mg/L).

Experimental methods

All the experiments including soluble COD (5220 D. Closed reflux, Colorimetric method), MLSS and MLVSS (2540 G. Total, Fixed and Volatile Solids in solid and semisolid samples), TSS (2540 D. Total Suspended Solids dried at 103~105°C), turbidity (2130 B. Nephelometric Method), Dissolved Oxygen (DO) (4500-O G.

Membrane Electrode method) and pH (4500-H+ B. Electrometric method), were carried out according to the Standard Methods for Water and Wastewater Examination (APHA, AWWA and WEF, 1992).

RESULTS

Four SBRs were operated under the same conditions and at various SRTs. The effluent qualities and the bio-sludge properties of the reactors are summarized in Table 1.

Table 1: Effluent quality and the bio-sludge properties of aerobic SBRs at various SRTs

Reactor (SBR)	R1	R2	R3	R4
Effective volume (L)	5.5	5.5	5.5	5.5
Wastewater flow rate (L/d)	3.5	3.5	3.5	3.5
HRT (d)	1.57	1.57	1.57	1.57
SRT (d)	5	10	15	20
OLR (g COD/m^3.d)	1372 ± 34	1362 ± 33	1402 ± 14	1394 ± 36
Effluent COD (mg/L)	108 ± 31	97 ± 30	91 ± 30	84 ± 25
COD Removal (%)	95.0 ± 1.4	95.4 ± 1.4	95.9 ± 1.4	96.2 ± 1.1
Effluent TSS (mg/L)	32 ± 7	34 ± 5	17 ± 5	15 ± 4
Effluent turbidity (NTU)	4.83 ± 2.2	5.89 ± 1.5	4.74 ± 1.8	4.37 ± 2.2
MLSS (mg/L)	1824 ± 461	2694 ± 632	3210 ± 1248	3864 ± 1526
MLVSS/ MLSS (%)	87 ± 2	88 ± 1	88 ± 2	87 ± 2
Excess sludge (g/d)	2.01 ± 0.51	1.48 ± 0.35	1.18 ± 0.46	1.06 ± 0.42
Total produced sludge (g)	24.08	17.78	14.12	12.75
F/M (1/d)	0.83± 0.37	0.54 ± 0.16	0.52 ± 0.26	0.44 ± 0.22
U (1/d)	0.79 ± 0.36	0.51 ± 0.16	0.5 ± 0.25	0.42 ± 0.21
SVI (mL/g)	75 ± 40	41 ± 12	44 ± 14	50 ± 11

COD Removal efficiency

In spite of insignificant change of COD removal due to SRT, the effluent COD of reactors decreased as the SRT increased (Table 1). Reactors 4 and 1 with SRT of 20 and 5 d had the lowest and the highest effluent COD, respectively. Fig. 2 shows the COD removal efficiency for all SBRs. It should be pointed out that SRT had a little effect on COD removal efficiencies. However, as it shown in Fig. 3, the overall trend of COD removal efficiency vs. SRT shows an increasing rate with the correlation factor (R^2) of 0.99. This is mainly due to a higher biomass concentration for longer SRTs.

Soluble COD of the reactors in cycle 60 of operation were also examined during the reaction period. According to these results, more than 90 percent of influent COD were decreased within two hours of the reaction time as it shown in Fig. 4.

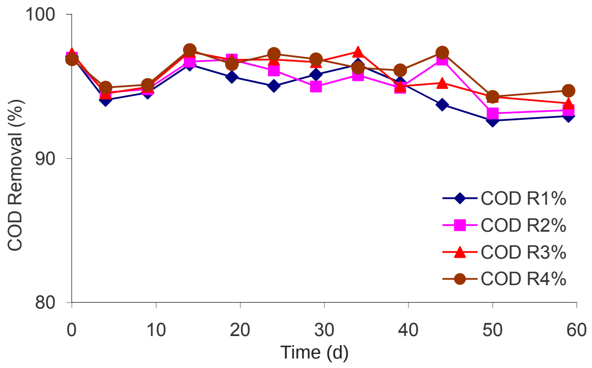

Fig.2: COD removal efficiency in SBRs

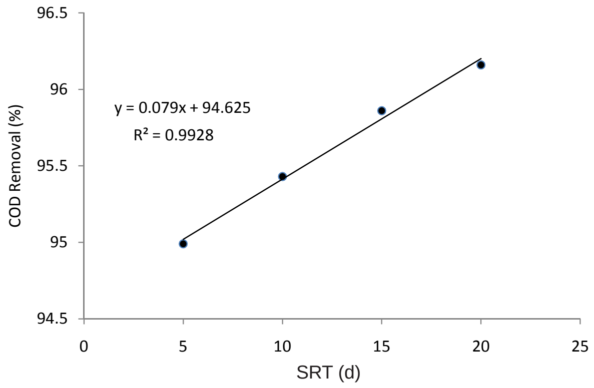

Fig.3: COD removal efficiency vs. SRT

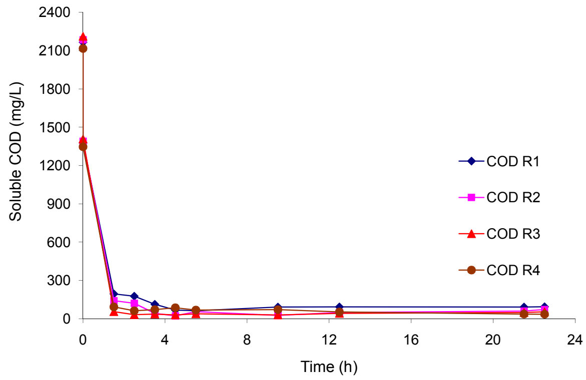

Fig.4: Hourly COD variation in reaction period

Effluent TSS and turbidity

As is shown in Table 1, no clear relation was observed between effluent TSS and turbidity with SRT. Reactor 4 with SRT of 20 d had the lowest effluent TSS and turbidity and vice versa reactor 2 with SRT of 10 d had the highest. The average effluent turbidity for reactor 1 to 4 with SRT of 5, 10, 15 and 20 d were 4.83, 5.89, 4.74 and 4.37 NTU, respectively, which are less than Iranian national effluent discharge standards (<50 NTU) (Iranian environmental protection regulations & standards., 2004).

Regarding the results obtained in this study, reactor 2 with SRT of 10 d, had the highest effluent TSS and turbidity of 34 mg/L and 5.89 NTU, respectively. Total suspended solid (TSS) concentration and turbidity in lower SRTs (5 and 10 d) was higher than that in longer SRTs (15 and 10 d) was higher than that in longer SRTs (15 and 20), however there was no clear relation between effluent quality (TSS and turbidity) and SRT.

F/M and specific utilization rate (U)

The F/M and specific utilization rate (U) values decreased with SRT. The highest and the lowest value of U ($U = (OLR_{in} - OLR_{eff})/MLSS$) were found in reactors 1 (0.79 d^{-1}) and reactor 4 (0.42 d^{-1}), respectively. Sirianuntapiboon *et al.* (2006a) obtained similar results where F/M of reactors with SRTs of 6.8, 8.5 and 10.1 d were 0.091, 0.047 and 0.029 d^{-1}, respectively which indicates a decreasing rate of F/M via SRT.

MLSS and MLVSS

Information on sludge concentration (MLSS and MLVSS) is necessary to understand the actual performance of the biological processes. Fig .5 shows the concentration of MLSS in the reactors within the operation period. As it mentioned in Table 1, SRT had directly influenced the biomass concentration of SBRs. The average amount of MLSS of R1 to R4 were found to be 1824, 2694, 3210 and 3864 mg/L respectively. In addition, the average amounts of MLVSS/MLSS were between 87-88 percent.

The amount of excess sludge decreased by SRT as the maximum of 2.01 g/d appeared in R1 with SRT 5 days and contrary the minimum of 1.06 g/d in R4 with SRT 20 days. The total produced sludge for R1 was 24 g, two times than that for R4 as 12 g. This mainly affects the overall cost of treatment process. As it is shown in fig.6, the amount of produced sludge versus SRT, had a decreasing rate of 92 percent (R^2= 0.921).

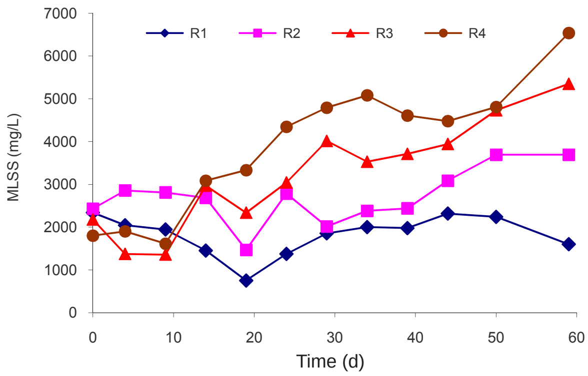

Fig.5: MLSS concentration of SBRs at different SRTs

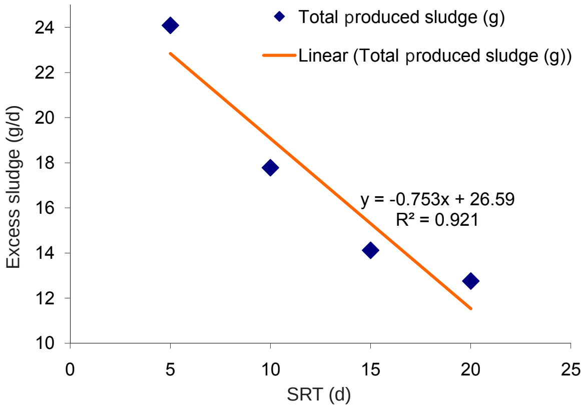

Fig.6: Total produced Sludge vs. SRTs

Sludge volume index (SVI)

Sludge volume index of 100 mL/g is generally known as the boundary of good settling characteristics and bulking problem (Mines *et al.* 1998; Kargi *et al.* 2002). All the reactors showed acceptable SVI. The highest and the lowest average of SVI belonged to the sludge of reactor 1 (75 mL/g) and reactor 2 (41 mL/g), respectively. Fig. 7 shows the values of sludge volume index of SBRs within the operation period.

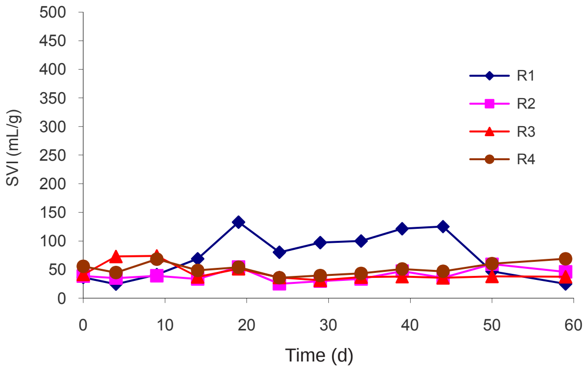

Fig.7. Sludge Volume Index (SVI) of bio-sludge of the reactors

DISCUSSION

Four SBRs operated under the same OLR_{in} (1400 $gCOD/m^3d$ with influent COD of 2200 mg/L); HRT (1.57 d) and the same operating cycles ran for 70 days (including 10 days of acclimatization) at different sludge retention times. According to the obtained results, SRT had a little effect on COD removal efficiencies. However, the overall trend of COD removal efficiency vs. SRT shows an increasing rate with the correlation factor (R^2) of 0.99 (Fig. 3). Some of earlier studies stated that even under different influent OLRs, the effect of SRT variation on COD removal efficiencies is insignificant and removal efficiency slightly changed. For instance, Mines *et al.* (1998) found that SRT had a little effect on COD removal for domestic wastewater treatment. They reported the COD removal of 83, 83 and 82 percent for SRTs of 9.3, 13.8 and 18.3 d, respectively. As a similar result, Yoong *et al.* (2000) studied wastewater containing phenol using SBRs with SRTs of 4, 6 and 27 d and found the average removal efficiencies of 97, 98 and 98 percent, respectively. Furthermore, Liao *et al.* (2001) observed COD removal efficiencies of 85, 85 and 84 percent for SRTs of 9, 11 and 21 d, respectively for treatment of a synthetic wastewater containing glucose and inorganic salts.

According to our results, TSS concentration and turbidity in lower SRTs (5 and 10 d) was higher than that in longer SRTs (15 and 20); however there was no clear relation between effluent quality (TSS and turbidity) and SRT. Similar results were also observed by other researches using different wastewater and OLRs. For example, Mines *et al.* (1998) obtained TSS of 17, 15 and 15 mg/L for SRTs of 9.3, 13.8 and 15d, respectively. In addition, Liao *et al.* (2006) obtained TSS of 30, 30, 33, 15 and 14 mg/L for SRTs of 4, 9, 11, 15 and 21 d, respectively.

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