INVESTIGATION OF INTERMITTENT CHLORINATION SYSTEM IN BIOLOGICAL EXCESS SLUDGE REDUCTION BY SEQUENCING BATCH REACTORS

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ABSTRACT
The excessive biological sludge production is one of the disadvantages of aerobic wastewater treatment processes such as sequencing batch reactors. To solve the problem of excess sludge production, oxidizing some of the sludge by chlorine, thus reducing the biomass coefficient as well as the sewage sludge disposal may be a suitable idea. In this study, two sequencing batch reactors, each with 20 L volume and controlled by on-line system were used. After providing the steady state conditions in the reactors, sampling and testing of parameters were done during 8 months. The results showed that during the solid retention time of 10 days the kinetic coefficient of Y and K_d were 0.58 mg biomass/mg COD and 0.058/day, respectively. At the next stage, different concentrations of chlorine were used in the reactors intermittently. Results showed that 15 mg chlorine/gMLSS in the reactor was able to reduce the yield coefficient from 0.58 to 0.3 mg biomass/mg COD. In other words, the biological excess sludge was reduced about 48%. But the soluble chemical oxygen demand increased slightly in the effluent and the removal percentage decreased from 95% in the blank reactor to 55% in the test reactor.

Key words: Biological sludge, chlorine, sludge oxidation, yield coefficient, specific oxygen uptake rate, sludge volume index

INTRODUCTION
One of the aerobic processes in wastewater treatment is Sequencing Batch Reactor (SBR) which in recent years has been widely used to treat industrial and municipal wastewater because of its low cost and suitable efficiency in pollutant removal. The process is composed of five stages as filling, reaction, settling, effluent and idle (USEPA, 1999; Metcalf and Eddy 2003; Wisaam *et al*., 2007).

Excess sludge treatment and disposal currently represents a rising challenge for wastewater treatment plants (WWTPs) due to economic, environmental and regulation factors (Canales *et al.,* 1994). Sludge production is one the major features undertaken in the biological treatment of wastewater. The bulk of the produced biological sludge and its quality specifications depend on both the quantitative and qualitative properties of the wastewater and the treatment process as well as its operating conditions. The relatively high production of the biological sludge excess is considered as one of the major drawbacks of the aerobic processes involved in wastewater biological treatment. In the mean time, about 40 to 60 percent of the investment expenses and more than 50 percent of the operation and maintenance expenses of the activated sludge treatment plants have to do with treating the sludge coming from the wastewater treatment plants (Canales *et al.,* 1994; Liu *et al.,* 2001; Wang *et al*., 2006).

The important methods for the reduction of excess sludge are: endogenous metabolism (Liu *et al.,* 2001; Liu, 2003); uncoupling metabolism (Low *et al.,* 1998; Liu *et al.,* 2000; Low *et al.,* 2000; Xia Ye *et al*., 2008); increase of dissolved oxygen in reactor (Abbassi *et al.,* 2000); oxic settling- anaerobic (Sabya *et al.,* 2003; Wang *et al*., 2008); ultrasonic cell disintegration (Yoon

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et al., 2003; Hoon *et al.,* 2004); alkaline heat treatment (Rocher, 2001; Yan *et al*., 2008); predation on bacteria (Huang *et al.,* 2007; Liang *et al.,* 2006; Liang *et al.,* 2006). Also oxidation of a part of produced sludge is done by oxidizing materials such as chlorine and ozone (Yasui, 1996; Sakai, 1997; Low *et al.,* 1999; Saby *et al.,* 2002; Liu, 2003).

Adding chlorine and ozone to sludge return line can also affect the reduction of sludge excess and the improvement as well as control of filamentous bulking. As an alternative solution of sludge reduction, recently a chlorination-combined activated sludge process had been developed for minimizing excess sludge production (Saby *et al.,* 2002). This chlorination-combined activated sludge process is similar to the ozonation activated sludge process, i.e. excess sludge was subjected to a chlorine dosage of 133 mg/gMLSS/d and the chlorinated liquor was then returned to the aeration tank. Compared to the control process without chlorination, the sludge production could be reduced by 65% in the chlorination-activated sludge system, which is comparable with the cutting percentage of sludge production in the ozonation-activated sludge process.

In the ozonation-activated sludge process, the improved sludge settleability and less influence on the effluent quality has been observed (Kamiya, 1998); however, the chlorination treatment resulted in a poor sludge settleability and significant increase of soluble Chemical Oxygen Demand (COD) in the effluent (Saby *et al.,* 2002). It is expected that these potential problems can be minimized by using membrane separation units instead of the conventional sedimentation tanks.

From the point of view of operation cost, the chlorination-activated sludge process would have advantages over the ozonation-activated sludge system as described earlier. Since chlorine is a weak oxidant as compared to ozone, the dosage of chlorine used in the chlorination-activated sludge process is about 7–13 times higher than that of ozone applied in the ozonation-activated sludge process. It is well known that ozone has much higher oxidation power than chlorine, releases limited by-products and is non-reactive with ammonia (Wojtenko, 2001). However, in the chlorination-activated sludge process, the formation of undesirable chlorinated by-products would occur.

Previous researches have shown that when raw water was reacted with chlorine, the yield of trihalomethanes (THMs) was increased as a function of the input amount of chlorine (Park, 2001), while long-term chlorine demand and the formation of THMs could follow a second-order kinetics (Gallard, 2002). Although the chlorination-activated sludge process is cost-effective over the ozonation-activated sludge system, chlorination-generated potential harmful byproducts would pose serious challenge to full-scale application of this technique (Liu, 2003).

In this research, different concentrations of chlorine in the reactor were used intermittently to reduce the excess biological sludge production.

MATERIALS AND METHODS

Reactor

The pilot consisted of two cylindricals plexyglass sequencing batch reactors (25 cm diameterÍ60 cm height), with net volume of 20 L and treatment capacity of 10 L per cycle; In - depth diffuser membrane- like bubble–size 1 to 3 mm as ECOFLEX 250 CV made by the American Diffuser company was used to aerate the reactor. Fig. 1 shows the schematic view of sequencing batch reactors (SBR) system.

The programmable logic controller (PLC) was used to operate the system. The run times of two reactors was selected in the same manner according to the type and characteristics of influent wastewater and are shown in Table 1.

Table 1: Sequence of operation time in SBR pilot

Stages	Time
Fulfilling	3 min
Aeration	4 h
Settling	105 min
Drainage	12 min
Idle	1 min

Synthetic wastewater characteristics

The synthetic wastewater was provided through mixing of 50 mg industrial milk powder and 100 L of urban treated water. The characteristics of operational conditions in the experiments are presented in Table 2.

Table 2: Summary of the operational conditions

Characteristics	Reactor-1 (blank)	Reactor-2 (tested)
Reactor volume (L)	20	20
SRT (day)	10	10
Chlorine concentration (mg/L)	0	0 to 20
Influent COD (mg/L)	600	600
Influent BOD_5 (mg/L)	350	350
Nitrogen (as TKN) (mg/L)	30.7	30.7
Phosphorus (mg/L)	10.5	10.5

Pilot start up

The seed was chosen from the returned activated sludge of Ikbatan, wastewater treatment plant located in west of Tehran. To operate the system about 4 L of the aforementioned sludge was used for a SBR reactor with capacity of 20 L. Next, the synthetic wastewater was added to the reactor.

Two weeks aeration and reaction was performed to establish the flocs. During this reaction process, synthetic wastewater was added to the reactor every day. After this stage, the SBR was started up with 5 cycles, i.e. fulfilling, reaction, wastewater drainage, sludge drainage and idle. The parameters of COD, suspended solids (SS) and pH of wastewater were tested and compared with previous data. After 2 weeks of pilot run, the effluent COD data were close to eachother, demonstrating the start up ending.

After reaching to steady state and stable situation in pilot running, the parameters of chemical oxygen demand (COD), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solid (MLVSS), sludge volume index (SVI), specific oxygen uptake rate (SOUR), residual chlorine and yielding kinetics were tested during 8 months.

The tests were performed according to standard methods for the examination of water and wastewater (APHA, 1995).

Due to the changes in the sludge age and chlorine concentration, at least 2 weeks were considered for the system to be adopted with the new situation. Then, data was gathered after stable condition. The suspended solid concentration in SBR and effluent wastewater COD were considered as factors of the stability condition. A given chlorine concentration was injected to the reactor. According to standard methods for water and wastewater examination, this process was triplicated, and the mean of the results was registered (APHA, 1995).

Determination of Y and K_d

In order to determine the synthetic efficiency of Y (the biomass production efficiency) and the endogenous efficiency (K_d), its required either to operate in different cell retention time (at least five cell retention times) or to alter at least four concentrations.

The following facts are discussed in this study:

To determine the biosynthetic efficiencies, especially biomass production coefficient (Y) the biomass production change in time unit according to COD change consumed in time unit during the 10–day returned time (the max removal efficiency of COD)was used.

In high chlorine addition, it is not possible to determine the biosynthetic coefficients by a graph because of slight increase of COD as a result of breaking and oxidation of MLSS. Thus the biomass co-efficiency production during yield operation can be calculated by equations (1) and (2), in which the resulting value does not differ much from the biosynthetic co-efficiency determining by graph without the chlorine added or the low amount addition of chlorine to some parts of sludge.

$$dX/dt = Y\, dS/dt \qquad (1)$$

where:

dX/dt=the increase rate in biomass concentration or MLSS, mg/L

dS/ dt=the removal rate of substrate or COD, mg/L

$$Y = \frac{X_0 - X}{S_0 - S} \qquad (2)$$

Where: S and S_0 are the primary and ultimate substrate concentrations (mg/L), and X and X_0 are the primary and ultimate biomass concentrations (mg/L), respectively.

It should be noted that in this study, the temperature was maintained by the adjustable aquarium heater at 20 to 22ºC and the dissolved oxygen was kept as much as 1.5 to 2 mg/L.

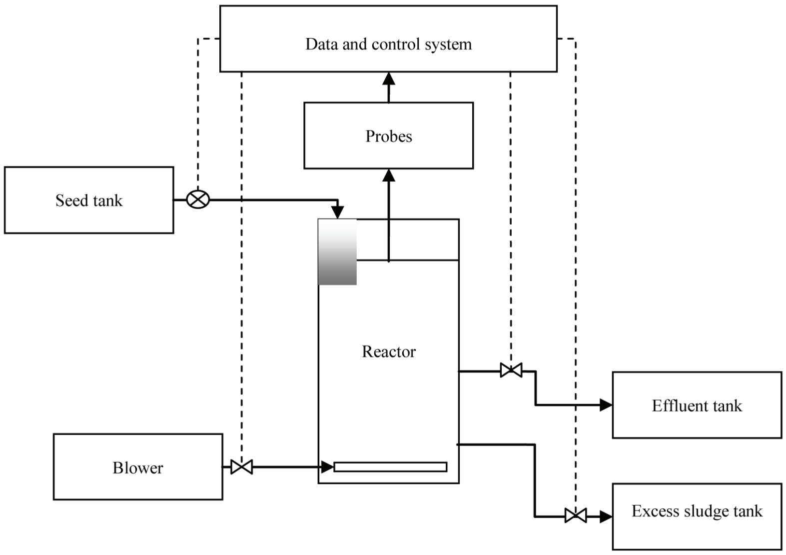

Fig. 1: The general schematic view of SBR pilot

RESULTS

Table 3 shows the amount of different COD in 10 days SRT to determine Y and K_d.

As can be seen in Fig. 2, different COD concentrations of 300 ,400, 600 and 800 mg/L , were used and a 10 days retention time having operated in growth stable phased with high efficiency was used to minimize the phase effect of logarithmic growth, as well as endogenous.

Table 3: COD concentrations for determination of Y and K_d (SRT=10 days)*

Reaction time (h)	COD	MLSS	COD	MLSS	COD	MLSS	COD	MLSS
0	800	1250	600	1350	400	1550	300	1410
0.5	770	1230	420	1570	205	1500	102	1550
1	535	1970	290	2050	123	1710	81	1600
1.5	313	2450	107	2300	93	1685	57	1760
2	198	2630	91	2450	73	1900	35	1850
3	130	2820	69	2630	47	2250	15	2000
4	54	2726	48	2532	13	2381	5	2238
$\overline{X}$		2171		2150		1889		1796
dX/X		0.68		0.55		0.44		0.35
dS/X		0.35		0.25		0.20		0.16

* All parameters as mg/L

According to Fig. 2, the coefficients were determined as K_d=0.056/day and Y=0.58 mg biomass/mg COD, during the 10 day cell retention time without the addition of chlorine.

The biosynthetic coefficient rate of biomass (Y) was calculated in the different chlorine concentrations injected into the reactor; as the Table 4 shows in 5 and 15 mg chlorine/gMLSS in reactor, the values of biomass production were 0.48 and 0.03 mg biomass/mg COD, respectively.

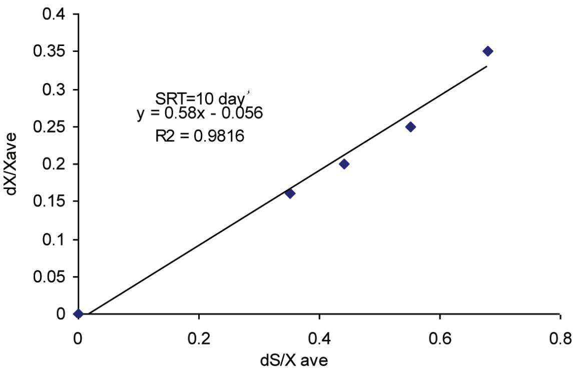

Fig. 2: Determination of Y and K_d (no-chlorine addition; SRT=10 days)

As it can be seen in Table 4, in the state of no-chlorine with COD=600 mg/L, the yield coefficient was 0.58 mg biomass/mg COD and the removal of COD was 95%.
The effects of different chlorine dosages in SBR reactor on the COD removal and SVI are shown in Figs. 3 and 4, respectively.
Figs. 5 and 6 shows the effect of different chlorine dosages on SOUR and Yield coefficient. According to Figs. 5 and 6 with increasing of chorine dosage added to reactor the oxygen consumption rate and yield coefficient decrease.
The effect of chlorine added to the reactor on the excess sludge reduction is presented in Fig. 5. As it can be seen, by increasing the chlorine dosages added to reactor, percentage of sludge reduction increases, so that percentage of sludge reduction reaches less than 49% in 15 mg chlorine dosage/gMLSS into the reactor.
Figs. 7 and 8 shows the effect of different chlorine dosages added to the reactor on the effluent BOD_5 and TSS. As it can be seen, chlorine increase will cause BOD_5 and TSS increase.

Table 4: Effect of chlorine addition on Y, SVI, SOUR, COD removal and residual chlorine

Amount of chlorine addition ($mgCl_2$/gMLSS)	Y mg biomass/ mg COD	Residual chlorine at the end of reaction (mg/L)	COD removal (%)	SVI (mL/g)	SOUR (mgO_2/h.gVSS)
0	0.58	0	95	90	19
5	0.48	0.05	88	64	16
10	0.36	0.8	82	55	12
15	0.3	1.2	55	33	9
20	0.16	3.5	30	0	3

Fig. 3: The effect of chlorine dose on COD removal efficiency

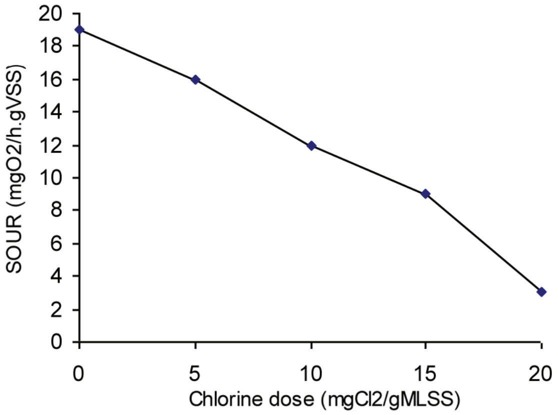

Fig. 5: The effect of chlorine dose on SOUR

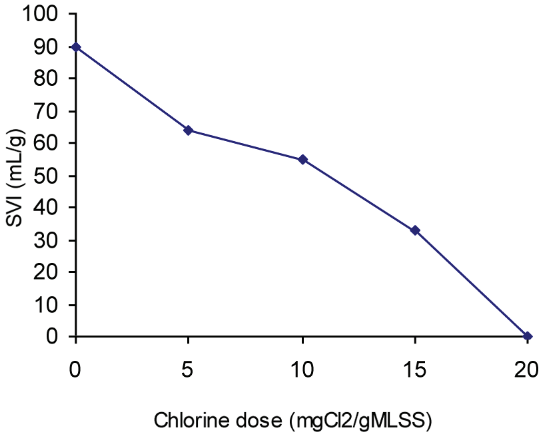

Fig. 4: The effect of chlorine dose on SVI

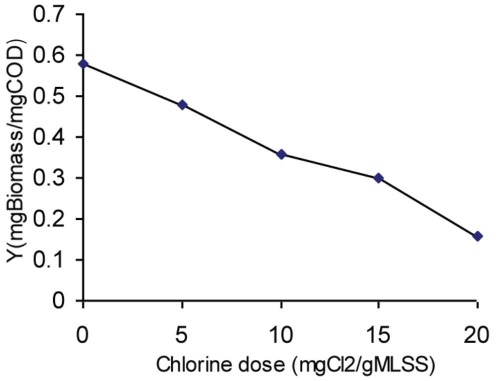

Fig. 6: The effect of chlorine dose on Yield

DISCUSSION

The effects of different chlorine dosages on COD removal coefficient

As shown in Fig. 3, despite of being effective in controlling filamentous bulking and minimizing the excess sludge production, chlorine caused a slight soluble COD increase in the effluent, further increasing the trihalomethane (THM) concentration in the effluent. Along the increase of chlorine, the COD removal performance decreased, and reached < 55% in 15 mg chlorine dosage/gMLSS; but the soluble COD in the effluent increased.

Fig. 7: The effect of chlorine dose on sludge reduction

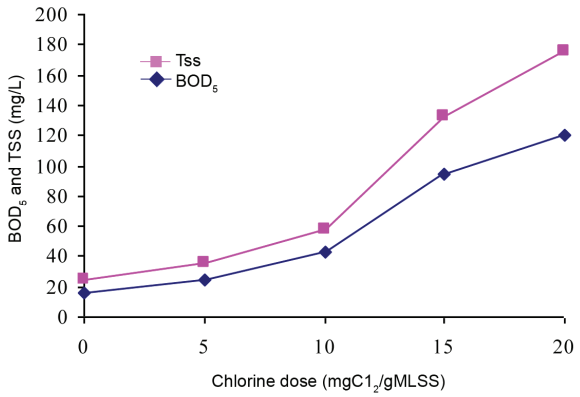

Fig. 8: The effect of chlorine dose on effluent BOD_5 and TSS

Since chlorine kills a lot of heterotrophic microorganisms in the reactor and oxidizes part of the biomass, the soluble COD, SCOD rate increased in the effluent. Saby (2002) reported that with the continuous chlorination at 0.066 g Cl_2/gMLSS to the reactor, the amount of SCOD increases.

The effect of different chlorine dosages on SVI

According to Fig. 4, as the rate of chlorine dosage addition increased, the SVI decreased in a way that with 15 mg chlorine dosage/gMLSS, SVI abated to around 33 mL/g; on the other hand, having increased the chlorine dosages, the MLVSS/MLSS ratio decreased, thus light increasing the specific weight of sludge. Yasui (1994), Sakai (1997) and Kamiya (1998) reported that the continuous ozonation to the activated sludge reactor, would be a useful technology for improving sludge settleability but Saby (2002) reported that the chlorination treatment resulted in a poor sludge settleability.

The effect of different chlorine dosages on SOUR

Along with the increase of dosages added to the reactor, oxygen consumption rate reduced because of the killing of a significant portion of microorganisms therefore the SOUR rate reduced in accordance with each mg of oxygen/hg of VSS (Fig. 5). As a result, in the chlorine dosages of 20 mg/gMLSS in the SBR reactor, SOUR was lowered to 3 mg O_2/hg VSS. This happens because of the inhibitory role of chlorine (Table 5).

The effect of different chlorine dosages on yield coefficient and sludge reduction

As shown in Figs. 6 and 7, by adding chlorine, the yield coefficient decreased. For instance 10 mg chlorine/gMLSS in reactor, caused the reduction of the excess sludge and as a result the yield coefficient was 0.36 mg biomass/mg COD. But

Table 5: SOUR and oxygen consumption rate in different conditions

Significance	Oxygen consumption rate	SOUR (mg/h.gVSS)
There is insufficient amount of solids in reactor for BOD load	high	More than 20
BOD removal is good and the sludge sedimentation is acceptable	normal	12-20
There is high amount of solids in reactor; or existence of toxic materials	low	Less than 12

its disadvantage is the slight increase of soluble COD in effluent. For example the removal of COD may reach to 30% by adding 20 mg chlorine/gMLSS, although this increase may not be obtainable in any excess sludge and the COD removal efficiency was lowered to 60%. In such amount of chlorine, many microorganisms in the reactor turned non viable and died. The reason of such a low coefficient is that chlorine plays the role of disinfection and oxidation, hence killing many microorganisms in the reactor, except for limited number of slime microorganisms which can tolerate (Saby *et al.,* 2002; Liu, 2003).

The results showed that the 15 mg chlorine per gram of MLSS in the reactor was able to reduce Yield coefficient from 0.58 to 0.3 mg biomass/ mg COD. In other words, the biological excess sludge reduced about 48%. As a consequence, no sludge was seen in 20 mg chlorine concentration/ gMLSS. Saby indicated that due to the continuous chlorination at 0.066g Cl_2/gMLSS to the reactor, the amount of excess sludge decreased about 65%.

The effect of different chlorine dosages on the effluent BOD5 and TSS

Fig. 8 illustrates that the increased chlorine dosage applied to the reactor resulted in an increase of the BOD_5 and TSS in the effluent. Without chlorine addition to the reactor, the effluent BOD_5 and TSS are 16 and 24 mg/L respectively with the chlorine dosages of 20 mg/g MLSS added, BOD_5 and TSS reached to 120 and 176 mg/L. Sakai (1997) reported that through the continuous ozonation at 11 gO_3/gMLSS to the reactor, the amount of BOD increases, although the amount of excess sludge decreases as 100%.

Finally, the use of chlorine is considered as one of the chemical methods for reducing the production of biological excess sludge. With the high chlorine concentration in to the reactor, a great number of microorganisms are deactivated or die, and some point of the biomass is oxidized. Consequently the amount of soluble COD in the effluent increased, while the amount of biological excess sludge in the 15 mg concentration of chlorine/gMLSS into the reactor reduced to 48.3%. In with high concentration of chlorine add in to the reactor (20 $mgCl_2$/gMLSS) no biological excess sludge was produced, but the COD removal percentage in the effluent reduced.

In Table 6 the comparison of results of this study with other researches performed in the field of reduction of excess sludge production with oxidation by ozone and chlorine is presented.

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Table 6: Literature data for reducing excess sludge production by oxidation

Operation conditions	Sludge reduction(%)	Effluent quality	References
Full scale: 550 kgBOD/d of industrial wastewater, continuous ozonation at 0.05g O_3/gMLSS	100	Increase of COD	Yasui, 1996
Full scale: 450 m^3 /d of municipal wastewater, continuous ozonation at 0.02g O_3/gMLSS	100	Slight increase of BOD	Sakai, 1997
lab scale, synthetic waste water, intermittent ozonation at 11g O_3/gMLSS(aeration tank)d	50	Nearly un affected	Kamiya, 1998
Pilot plant scale, synthetic wastewater, intermittent ozonation in SBR at: 1- 10 mg O_3/gMLSS 2- 18mg O_3/gMLSS 3- 22mg O_3/gMLSS	 29 55 100	Slight increase of COD	Takdastan, 2008
Chlorination:Bench scale in activated sludge , 20°C synthetic wastewater, 0.066 gCl_2/gMLSS	65	Significant increase of SCOD	Saby, 2002
Pilot plant scale, synthetic waste water, intermittent chlorination in SBR at: 1- 5 mg Cl_2/gMLSS 2- 10mg Cl_2/gMLSS 3- 15mg Cl_2/gMLSS	 17 38 48.3	Significant increase of SCOD	This study

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