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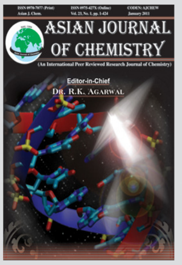

Survey on Chlorine Application in Sequencing Batch Reactor Waste Sludge in Order to Sludge Minimization

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The ultimate disposal of excess sludge generated from activated sludge processes has been one the most challenging problems for waste water treatment utilities. To solve the problem of excess sludge production, oxidizing the excess sludge by chlorine, thus reducing the biomass coefficient as well as the sewage sludge disposal is a fine idea. In this study, two sequencing batch reactors, each with 20 L volume were continuously operated with synthetic wastewater under the same conditions. After providing the steady state conditions in the reactors, sampling and testing of parameters were done for several months. During this period, one pilot unit was used as the reference system without chlorination of excess sludge, while another served as a testing unit. The results showed that during the solid retention time of 10 days the kinetic coefficient of Y and Kd were 0.60 mg biomass/mg COD and 0.068/day, respectively. At the next stage, different concentrations of chlorine were used in excess sludge and the chlorinated liquor was then returned to the aeration tank. Results showed that 0.26 g chlorine/g MLSS in return excess sludge to the reactor was able to reduce the yield coefficient from 0.60 to 0.3 mg biomass/mg COD. In other words, the biological excess sludge was reduced *ca.* 50 %. But the soluble chemical oxygen demand increased slightly in the effluent and the removal percentage decreased from 95 % in the blank reactor to 56 % in the test reactor.

Key Words: Biological sludge, Chlorine, Sludge oxidation, Yield coefficient, 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[1-3]. Excess sludge treatment and disposal currently represents a rising challenge for wastewater treatment plants (WWTPs) due to economic, environmental and regulation factors[2]. Sludge production is one of 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, *ca.* 40 to 60 % of the investment expenses and more than 50 % 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[1-3,8,9]. The important methods for the reduction of excess sludge are: endogenous metabolism[3,5,8], uncoupling metabolism[9-12], increase of dissolved oxygen in reactor[13,14], oxic settling- anaerobic (OSA)[15,16], ultrasonic cell disintegration[6,12,17], alkaline heat treatment[7,16], predation on bacteria[18-20]. Also oxidation of a part of produced sludge is done by oxidizing materials such as chlorine and ozone[4,10,18,21,24]. 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[25]. 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 0.26 g/g mixed liquor suspended solids (MLSS) 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 50 % 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[24]. However, the chlorination treatment resulted in a poor sludge settleability and significant increase of soluble chemical oxygen demand (COD) in the effluent[22]. It is expected that these potential problems can be minimized by using membrane separation units instead of the conventional sedimentation tanks[24]. 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 *ca.* 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[15]. 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[23], while long-term chlorine demand and the formation of trihalomethanes could follow a second-order kinetics[21]. 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[8]. In this research, different concentrations of chlorine in excess sludge returned into the reactor were used intermittently to reduce the excess biological sludge production.

EXPERIMENTAL

The pilot consisted of two cylindricals plexyglass sequencing batch reactors (25 cm diameter, 60 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 250CV made by American Diffuser Company was used to aerate the reactor. Fig. 1 shows the schematic view of sequencing batch reactors (SBR) system.

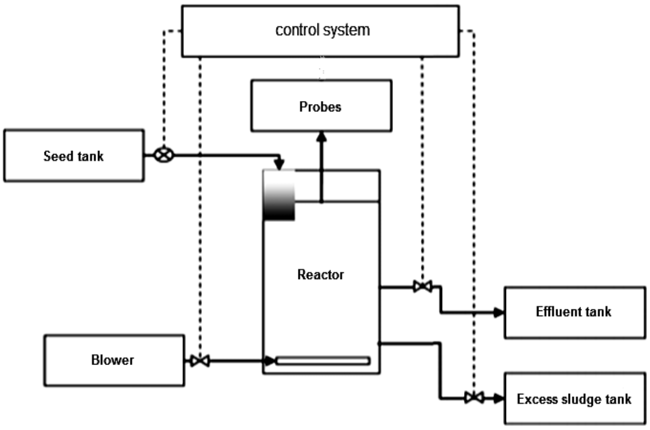

Fig. 1. General view of sequence batch reactor scheme

The progammable digital timers were 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 SEQUENCING BATCH REACTOR PILOT

Stage	Time (min)
Fulfilling	3
Aeration	240
Settling	105
Drainage	12
Idle	1

Synthetic wastewater characteristics: The synthetic wastewater was provided through mixing of 40 mg industrial milk powder and 50 L of urban treated water. The characteristics of operational conditions in the experiments are presented in Table-2.

TABLE-2
SUMMARY OF THE OPERATIONAL CONDITION

Characteristics	Rector-1 (blank)	Rector-1 (tested)
Reactor volume (L)	20	20
SRT (day)	10	10
Chlorine concentration (mg/L)	0	0-20
Influent COD (mg/L)	600	600
Influent BOD (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 Choneybe, wastewater treatment plant located in west of Ahwaz. To operate the system *ca.* 4 L of the aforementioned sludge was used for a sequencing batch 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 sequencing batch reactor 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), sludge volume index (SVI), residual chlorine and yielding kinetics were tested during several months. The tests were performed according to standard methods for the examination of water and wastewater (APHA, 2005). 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 sequencing batch reactor 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, 2005).

Determination of Y and Kd: In order to determine the synthetic efficiency of Y (the biomass production efficiency) and the endogenous efficiency (Kd), its required either to operate in different cell retention time (at least five cell retention times) or to alter at least three 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 mixed liquor suspended solids (MLSS). Thus the biomass co-efficiency production during yield operation can be calculated by eqns. 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.

$$dX/dt = Y\ dS/dt \tag{1}$$

where: dX/dt = the increase rate in biomass concentration or MLSS, mg/L; dS/dt = the removal rate of substrate or COD, mg/L.

$$Y = X^0 - X/S^0 - S \tag{2}$$

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 at 20 to 22 ºC and the dissolved oxygen was kept as much as 1.5 to 2 mg/L.

RESULTS AND DISCUSSION

Table-3 shows the amount of different COD in 10 days SRT to determine Y and Kd. As can be seen in Fig. 2, different COD concentrations of 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 Kd (SRT = 10 DAYS)

Reaction time (h)	COD	MLSS	COD	MLSS	COD	MLSS
0	800	1243	600	1360	400	1403
0.5	773	1222	408	1550	202	1551
1.0	534	1964	292	2020	119	1601
1.5	301	2425	101	2310	94	1723
2.0	194	2610	89	2390	78	1854
3.0	127	2808	62	2601	51	2050
4.0	51	2721	45	2502	12	2228
X	–	2142	–	2104	–	1773
dX/X	–	0.69	–	0.54	–	0.46
dS/X	–	0.35	–	0.26	–	0.21

All parameters as mg/L

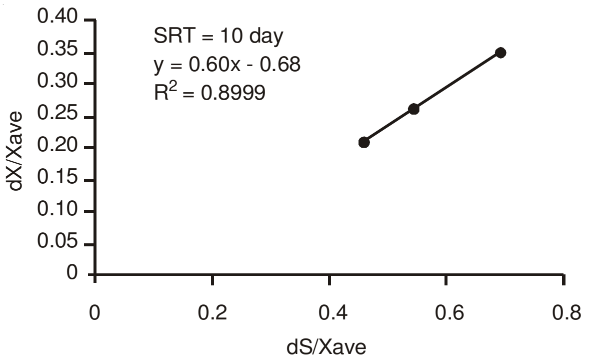

Fig. 2. Determination of Y and Kd (no-chlorine addition; SRT = 10 days)

According to Fig. 2, the coefficients were determined as Kd = 0.068/day and Y = 0.60 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; as the Table-4 shows in 0.06 and 0.26 g chlorine/g MLSS in excess sludge return into the reactor, values of biomass production were 0.45 and 0.3 mg biomass/mg COD, respectively.

As it can be seen in Table 4, in the state of no-chlorine with COD = 600 mg/L, the yield coefficient was 0.6 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. Fig. 5 shows the effect of different chlorine dosages on yield coefficient. According to Fig. 5 with increasing of chorine dosage added to reactor the yield coefficient decrease. The effect of chlorine added to the reactor on the excess sludge reduction is presented in Fig. 6. As it can be seen, by increasing the chlorine dosages added in excess sludge returned to the ractor to 0.26 g chlorine/gMLSS, percentage of sludge reduction increases, so that percentage of sludge reduction reaches less than 50 % in the reactor.

Effects of different chlorine dosages on COD removal: As shown in Fig. 3, despite of being effective in controlling filamentous bulking and minimizing the excess sludge

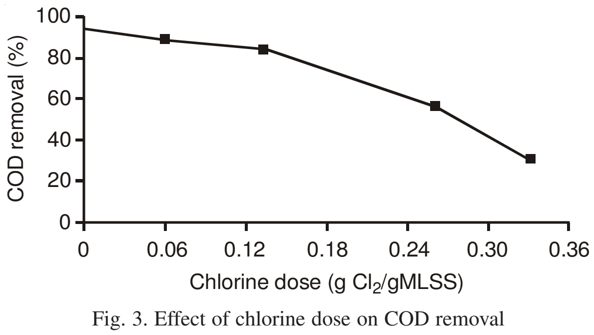

Fig. 3. Effect of chlorine dose on COD removal

TABLE-4
EFFECT OF CHLORINE ADDITION ON Y, SVI, COD REMOVAL AND RESIDUAL CHLORINE

Amount of chlorine addition (g Cl_2/gMLSS	Y mg Biomass/mg COD	Residual chlorine at the end of reaction (mg/L)	COD removal (%)	SVI (mL/g)	Sludge reduction (%)
0	0.60	0	95.0	94	0
0.06	0.45	0	89.6	68	25
0.13	0.37	0.02	84.0	59	38
0.26	0.30	0.16	56.0	38	50
0.33	0.15	0.31	30.0	–	75

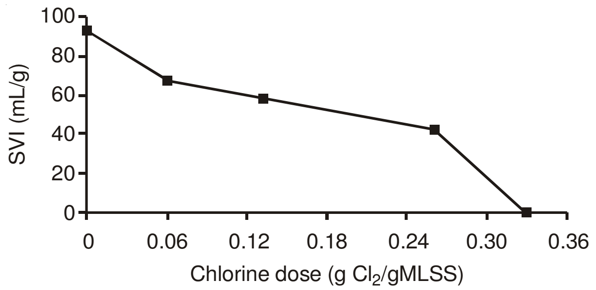

Fig. 4. Effect of chlorine dose on SVI

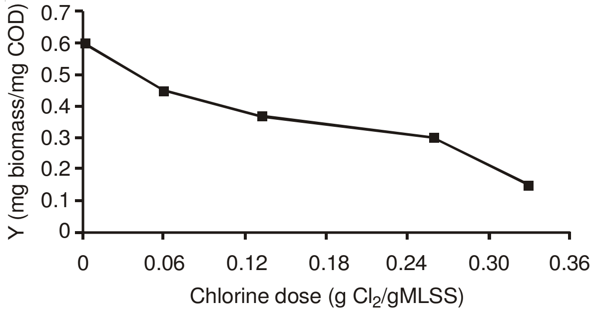

Fig. 5. Effect of chlorine dose on yield

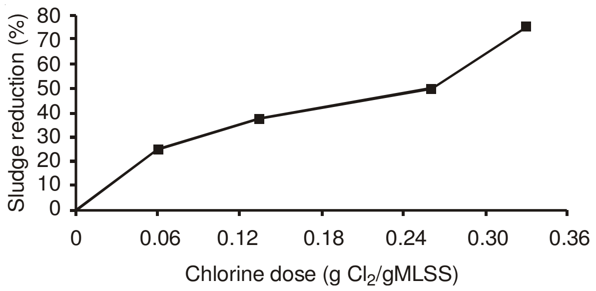

Fig. 6. Effect of chlorine dose on sludge reduction

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 < 56 % in 0.26 g chlorine dosage/gMLSS; but the soluble COD in the effluent increased.

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 *et al.*[25] reported that with the continuous chlorination at 0.066 g Cl$_2$/gMLSS to the reactor, the amount of COD increases.

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 0.26 g chlorine dosage/gMLSS, SVI abated to around 38 mL/g; Sakai *et al.*[12] and Kamiya *et al.*[22] reported that the continuous ozonation to the activated sludge reactor, would be a useful technology for improving sludge settleability, but Saby *et al.*[25] reported that the chlorination treatment resulted in a poor sludge settleability.

Effect of different chlorine dosages on yield coefficient and sludge reduction: As shown in Figs. 5 and 6, by adding chlorine, the yield coefficient decreased. For instance 0.13 g chlorine/gMLSS in excess sludge returned into the reactor, caused the reduction of the excess sludge and as a result the yield coefficient was 0.37 mg biomass/mg COD. But its disadvantage is the slight increase of soluble COD in effluent. For example the removal of COD may reach to 30 % by adding 0.33 g chlorine/gMLSS 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[8,25].

The results showed that the 0.26 g chlorine per gram of MLSS added in excess sludge was able to reduce yield coefficient from 0.6 to 0.3 mg biomass/mg COD. In other words, the biological excess sludge reduced *ca.* 50 %. As a consequence, no sludge was seen in 0.36 g chlorine concentration/gMLSS. Saby *et al.*[25] indicated that due to the continuous chlorination at 0.066g Cl$_2$/gMLSS to the reactor, the amount of excess sludge decreased *ca.* 65 %.

Conclusion

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 excess sludge returned into 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 0.26 g concentration of chlorine/gMLSS reduced to 50 %. With high concentration of chlorine added in excess sludge return in to the reactor (0.36 gCl$_2$/gMLSS) no biological

TABLE-5
COMPARISON OF RESULTS IN THE REDUCTION OF EXCESS SLUDGE PRODUCTION

Operation condition	Sludge reduction	Effluent quality	Ref.
Full scale: 550 kgBOD/d of industrial wastewater, continuous ozonation at 0.05 g O$_3$/gMLSS	100	Increase of COD	16
Full scale: 450 m^3/d of municipal wastewater continuous ozonation at 0.02 g O$_3$/gMLSS	100	Slight increase of BOD	12
Lab scale, synthetic wastewater intermittent ozonation at 11 g O$_3$/gMLSS (aeration tank) d	50	Nearly un affected	22
Pilot plant scale, synthetic wastewater intermittent ozonation in SBR at:			
1. 10 mg O$_3$/gMLSS	29	Slight increase of COD	24
2. 28 mg O$_3$/gMLSS	55		
3. 22 mg O$_3$/gMLSS	100		
Chlorination: Bench scale in activated sludge, 20 ºC synthetic wastewater 0.066 g Cl$_2$/gMLSS	65	Significant increase of SCOD	25
Pilot plant scale, synthetic wastewater intermittent chlorination in SBR at:			
1. 0.06 g Cl$_2$/gMLSS	25	Significant increase of SCOD	Present study
2. 0.26 g Cl$_2$/gMLSS	50		
3. 0.36 g Cl$_2$/gMLSS	100	Increase of COD	

excess sludge was produced, but the COD removal percentage in the effluent reduced. Table-5 shows the comparison of results of this study with other performed researches in the reduction of excess sludge production.

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