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Biological Excess Sludge Reduction in Municipal Wastewater Treatment by Chlorine

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As an alternative solution of sludge reduction, recently a chlorination-combined aerobic biological process such as activated sludge has been developed for minimizing excess sludge production. In this study, Two sequencing batch reactor (SBR) reactors with of 20 L being controlled by on-line system are used. After providing the steady state in the reactors, along the 6 month research sampling and testing parameters such as chemical oxygen demand (COD), mixed liquid suspended solid (MLSS), mixed liquid volatile suspended solid (MLVSS), dissolved oxygen (DO), specific oxygen uptake rate (SOUR), sludge volume index (SVI), residual chlorine and yield (Y) coefficient were done. The results showed that during the solid retention time of 10 days the kinetic coefficient of Y (the biomass production efficiency) and K_d (endogenous efficiency) was $0.58\left(\frac{\text{mg Biomass}}{\text{mg COD}}\right)$ and $0.58\left(\frac{1}{\text{day}}\right)$, respectively. At the next stage of research, different concentrations of chlorine in the reactor were used intermittent to reduce the excess biological sludge production. The results showed that the chlorine concentrated as 0.23 g per gram MLSS of 1 L of return sludge to the reactor is able to reduce the biomass coefficient from 0.58 to 0.33 (with approximate 45 % reduction of excess sludge) but the soluble COD slightly increased in the effluent. Besides the COD removal coefficient has decreasingly changed from 95 % in blank reactor to 80 %. In the 0.32 g chlorine/g MLSS of 1 L of return sludge to the reactor almost no excessive sludge was produced and the COD removal coefficient went down to less than 44 %. While the amount of SOUR and SVI in this consumed chlorine concentration reduced 3 mgO_2/h.gVSS and 17 mL/g, respectively.

Key Words: Sequencing batch reactor, Biological sludge, Chlorine, Oxidation of sludge, Yield, Specific oxygen uptake rate, Sludge volume index.

INTRODUCTION

The basic function of a wastewater biological treatment process is to convert soluble organics to carbon dioxide, water and bacterial cells. The produced cells need to be separated from the purified water and disposed of in a concentrated form called excess sludge. The excess sludge generated from the biological treatment

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process is a secondary solid waste that must be disposed in a safe and cost-effective way. So far, the ultimate disposal of excess sludge has been one of the most expensive problems faced by wastewater utilities, *e.g.* the treatment of the excess sludge may account for up to 65 % of the total plant operation cost one of the aerobic processes in waste water 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 5 stages as filling, reaction, settling and effluent and idle[1-3].

The biological sludge excess is as heavy as 1.005, with the solid concentration of totally 0.5 to 1.0 % which is composed of 70 to 90 % of organic materials. The rate of the secondary sludge production depends on the applied biological degradation and such procedural conditions as sludge age, temperature and the organic along with hydraulic load rate in the biological unit. The annual rate of secondary sludge produced by the activated sludge system is estimated as of 1.5 to 2.5 L per person in a day[1,3].

Reaching reduction in the rate of biological sludge production. In wastewater treatment process was raised when the attention was drawn toward the difficulties and expenses akin to treatment and disposal of activated sludge. Besides current rules and standards of sludge reuse and disposal for different organic and mineral pollutants as well as pathogens has caused the experts in wastewater treatment to reform the biological treatment methods and to devise ways for sludge to be produced less. In other words, if the problem with sludge excess production is removed by reducing the sludge production in biological process of wastewater treatment, such problems in treatment and disposal of sludge will significantly be controlled. Considerable costs of operation as well as sludge treatment process on one hand and the tough regulations and standards set to reuse and/or remove the sludge coming from the wastewaters treatment on the other hand have caused the methods of reducing the sludge production during the aerobic processes of wastewaters treatment to attract more attention[2,4].

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 the major features of 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 waste water 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 waste water biological treatment. In the mean time, about 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[2,3,5].

There is therefore considerable impetus to explore and develop strategies and technologies for reducing excess sludge production in biological wastewater treatment processes[2,5-7]. (i) Endogenous metabolism[3,5,8]; (ii) uncoupling metabolism[9-12]; (iii) increase of DO in reactor[13,14]; (iv) oxic settling-anaerobic (OSA)[15,16]; (v) ultrasonic cell disintegration[6,12,17]; (vi) alkaline heat treatment[7,16]; (vii) predation on bacteria[18-20]; (viii) oxidation of a part of produced sludge is done by such oxidizing materials as chlorine and ozone[4,8,10,21-24].

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 subject to a chlorine dose of 133 mg g^{-1} MLSS day^{-1} 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 was observed[22]. However, the chlorination treatment resulted in a poor sludge settleability and significant increase of soluble 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 research showed 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 THMs 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].

EXPERIMENTAL

In this research, the two sequence batch reactors (SBR) used with cylindrical shape tank, type of plexiglass, inner diameter of 25 cm, 60 cm height and net volume of 20 L and treatment capacity of 10 L per cycle. Fig. 1 demonstrate the layout and schematic diagram of sequence batch reactors (SBR).

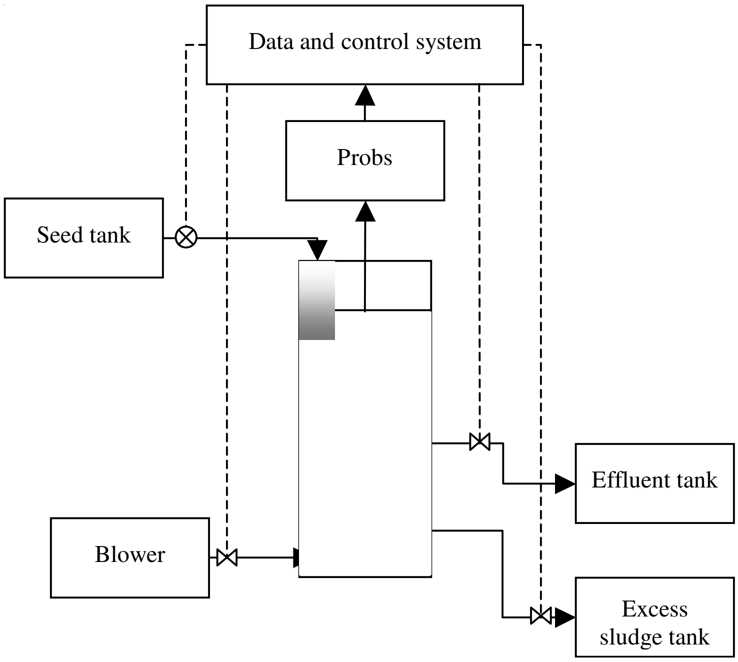

Fig. 1. General view of sequence batch reactor schematic

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

TABLE-1
SEQUENCE OF OPERATION TIME IN SEQUENCE BATCH REACTOR

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

*In the pilot run, the fulfilling time of the tank reduced to 70 s.

Synthetic wastewater characteristics: The synthetic wastewater of pilot prepared with mixing of 40 mg industrial dry and 100 L of tap water. The characteristic of wastewater in experiments are presented in Table-2.

TABLE-2
SUMMARY OF THE OPERATIONAL CONDITIONS

	Reactor-1 (blank)	Reactor-2 (tested)
Reactor volume (L)	20	20
SRT (day)	10	10
Chlorine concentration (g)	Chlorine is not added	0 to 0.32
Influent COD (mg/L)	600	600
Influent BOD_5 (mg/L)	350	350
Nitrogen (as TKN) (mg/L)	30.7	30.7
Phosphor (mg/L)	10.5	10.5

Pilot start up: First, seed of recalculated activated sludge of Ekbatan wastewater treatment plant used to start up of pilot which had not any problems such as bulking and other problems. And, the seed added with volume *ca.* 2 L per SBR with volume of 20 L and COD of 600 mg/L.

Aeration and reaction of 2 weeks performed to establish of flocs. But, in this stage only the reaction performed and food added every day. After this stage, SBR with run 5 cycles of fulfilling, drainage of wastewater and sludge started up. The parameters of COD, SS and pH of wastewater tested and compared with previous data. After 2 weeks of pilot run, effluent COD data were close to each others which this phenomenon was demonstration of start up ending.

After reaching to steady state and stable situation in pilot running, the parameters of COD, MLSS, MLVSS, SVI, SOUR, residual chlorine and yielding kinetics tested during 6 months.

The tests performed according to standard methods for the examination of water and wastewater[26].

Variable situation: Two weeks running (equal to 42 cycles of SBR running) considered to compliance with new situation because of changing the sludge age, residual chlorine during sludge age changes. Then, the data gathered after stable situations. The suspended solid concentration in SBR and effluent wastewater COD considered as indexes of situation stability. Sequence batch reactors run 3 times by different chlorine feed to one liter of sludge to reduce of excesses sludge production. Finally, the data gathered and only the average of data reported.

RESULTS AND DISCUSSION

Determination of Y coefficient in 10 days cell retention time in different chlorine feed to reactor: 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 the (at least four concentrations) thus to do so, 4 different COD concentrations as to 300, 400, 600, 800, 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.

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

The following facts are discussed in this study: to determine the biosynthetic efficiencies, especially biomass production co-efficiency (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.

According to Fig. 2, $K_d = 0/056 \frac{1}{\text{day}}$, $Y = 0/58 \frac{\text{mg Biomass}}{\text{mg COD}}$ during the 10 day cell retention time without the addition of chlorine. In higher chlorine added, it's 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 the following relation, in which the resulting value doesn't differ much from the biosynthetic co-efficiency shown in the graph without the chlorine added. The low amount addition of chlorine to some parts of sludge.

$$dX/dt = Y\ dS/dt$$

where: dx/dt = the increase rate in biomass concentration or MLSS (mg/L); ds/ dt = the removal rate of substrate or COD (mg/L).

$$Y = \frac{X_0 - X}{S_0 - S}$$

where S, S_0 are respectively the primary and ultimate substrate concentration (mg/L) and X, X_0 are respectively the primary and ultimate biomass concentration (mg/L).

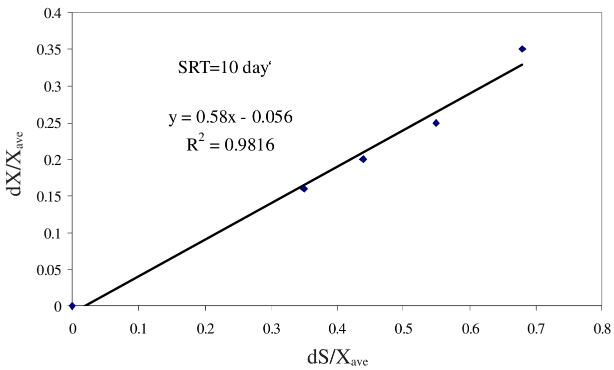

Fig. 2. Determination of Y and K_d in SRT = 10 days. Under no-chlorine-addition condition

The biosynthetic co-efficiency rate of biomass (Y) is in the different chlorine concentration injected into the reactor of Table-2, as the table shows under 5 and 15 mg chlorine per gram MLSS in reactor, the values of biomass production are 0.48 and 0.3 mg biomass/mg COD, respectively.

As can be seen in Fig. 3, in the state of no-chlorine with COD = 600 Mg/L, the yield co-efficient equals 0.6 mg biomass/mg COD and the removal of COD is 95 %. But by adding chorine to part of the return sludge the yield coefficient decreases, in a way that by adding 0.23 g chlorine per gram of MLSS to part of the return sludge, the yield coefficient will be 0.33 mg biomass/mg COD thus reducing the excess sludge. But its disadvantage is causing slight increase of soluble COD in effluent and the removal of COD reached *ca.* 44 % by adding 0.32 g of chlorine per gram of MLSS to 1 L of return sludge into the reactor resulted in no excess sludge, yet the COD removal coefficient was lowered to 44 %. In such amount of chlorine, many micro-organisms in the reactor turned non-viable and died. The cause of such a low co-efficiency is that chlorine plays the role of disinfection and oxidation, hence killing many micro-organisms in the reactor (except for limited number of slime microorganisms which can tolerate).

Effect of different chlorine dosage on COD removal: Fig. 3 shows the effect of different chlorine doses in one liter of return sludge to SBR reactor on the COD removal co-efficiency.

Despite being effective in controlling filamentous balking and minimizing the excess sludge production, chlorine causes the slight soluble COD increase in effluent, further it increased the THM in the effluent. According to Fig. 3 along the increase of chlorine, the COD removal coefficient decreases, so much so that COD removal co-efficiency reaches less than 44 % in 0.32 g chlorine dose per gram MLSS in 1 L of return sludge to the reactor but the soluble COD in effluent increases.

Since chlorine kills a lot of heterotrophic micro-organisms in the reactor and oxidizes part of the biomass, the soluble COD rate increases in the effluent.

Effect of different chlorine doses on SVI: According to Fig. 4, as the rate of chlorine dose addition to 1 L of the return sludge to reactor the SVI decreases in a way that with the 0.23 g chlorine dose per gram of MLSS in 1 L of return sludge, SVI abates to *ca.* 30 mL/g the other hand having increase the chlorine doses, the MLVSS/MLSS ratio decreases, thus light increasing the specific weight of sludge.

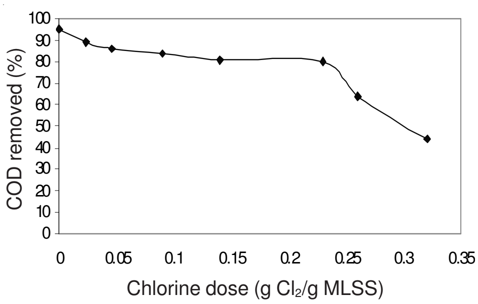

Fig. 3. Effect of chlorine does on COD removal efficiency

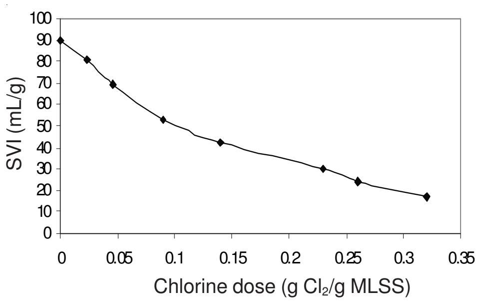

Fig. 4. Effect of chlorine does on SVI

TABLE-3
EFFECT OF ADDED CHLORINE ON Y, SVI, SOUR, COD REMOVAL AND RESIDUAL CHLORINE

Value of added chlorine per 1 L sludge (gCl_2/g MLSS)	Y $\left(\frac{\text{mgBiomas}}{\text{mg COD}}\right)$	Residual chlorine in the end of reaction (mg/L)	COD removal (%)	SVI (mL/g)	SOUR (mgO_2/h gVSS)	Sludge reduction (%)
0	0.58	0	95	90	18	-
0.023	0.50	0	89	81	18	16.7
0.046	0.45	0	86	69	13	25.0
0.090	0.41	0	84	53	9	31.7
0.140	0.36	0.01	81	42	7	40.0
0.230	0.33	0.09	80	30	5	45.0
0.260	0.00	0.15	60	24	3	–
0.320	–	0.30	44	17	3	–

Effect of different chlorine doses on SOUR: According to Fig. 5 along with the increase of doses added to 1 L of return sludge to reactor oxygen consumption rate reduces because of the killing of a significant portion of micro-organisms therefore the SOUR rate reduces in accordance with each mg of oxygen in hour per gram of volatile suspended solids. As a result in the chlorine doses of 0.32 g/g of MLSS in 1 L of return sludge to SBR reactor SOUR lowered to 3 mg O_2/h g VSS. This happens because of the chlorine's bring inhibitive (Table-4.)

TABLE-4
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
There is insufficient amount of solids in reactor for BOD load	Normal	12-20
There is high amount of solids in reactor or existence of toxic material	Low	Less than 12

Effect of different chlorine doses on yield coefficient: Fig. 6 shows the effect of different chlorine doses into SBR reactor on yield coefficient. The results showed that the 0.23 g chlorine per g of MLSS in 1 L of sludge return to the reactor is able to reduce yield coefficient from 0.58 to 0.33 $\left(\frac{\text{mg Biomass}}{\text{mg COD}}\right)$. In other words, the biological excess sludge by 45 %. No sludge was seen in 0.32 g chlorine/g MLSS of 1 L of return sludge to the reactor. In a chlorine dose more than above mentioned amount (0.32 g chlorine). Organic matter removal coefficient reduced as a result of the inhibitory effect of chlorine on microorganisms.

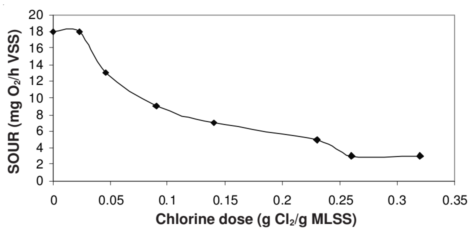

Fig. 5. Effect of chlorine does on SOUR

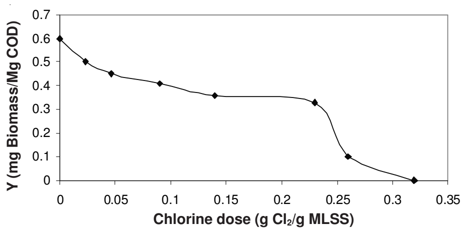

Fig. 6. Effect of chlorine does on yield

Conclusion

The use of chlorine is considered one of the chemical methods of reducing the production of biological excess sludge. With the high chlorine concentration into the reactor, a great number of microorganisms are deactivated or die and some of the biomass is oxidized. Where consequently the amount of soluble COD in the effluent increase, while the amount of biological excess sludge in the 0.23 g chlorine per gram of MLSS in 1 L of sludge return to the reactor reduces by 45 %. In the high concentration of chlorine to reactor (0.32 g concentration of chlorine to per g of MLSS in to the reactor) no biological excess sludge is produced, but the COD removal percentage in the effluent reduces. Table-5 shows the comparison of results of this study with other performed researches in the reduction of excess sludge production.

TABLE-5
LITERATURE DATA FOR REDUCING EXCESS SLUDGE PRODUCTION BY OXIDATION

Operation condition	Sludge reduction	Effluent quality	References
Full scale: 550 kgBOD/d of industrial waste water, continuous ozonation at 0.05 g O_3/g MLSS	100	Increase of COD	16
Full scale: 450 m^3/d of municipal waste water, continuous ozonation at 0.02 g O_3/g MLSS	100	Slight increase of BOD	12
Lab scale, synthetic waste water, intermittent ozonation at 11 g O_3/g MLSS (aeration tank) d	50	Nearly un affected	22
Pilot plant scale, synthetic waste water, intermittent ozonation in SBR at: 1. 10 mg O_3/g MLSS 2. 18 mg O_3/g MLSS 3. 22 mg O_3/g MLSS	 29 55 100	Slight Increase of COD	24
Chlorination: Bench scale in activated sludge, 20 ºC, synthetic wastewater, 0.066 g CI_2/g MLSS	65	Significant increase of SCOD	25
Pilot plant scale, synthetic waste water, intermittent chlorination in SBR at: 1. 0.09 g Cl_2/g MLSS 2. 0.23 g Cl_2/g MLSS 3. 0.32 mg Cl_2/g MLSS	 32 45 100	Significant increase of SCOD Increase of SCOD	Present study

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