Investigation of the Excess Sludge Reduction in SBR by Oxidizing Some Sludge by Ozone

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ABSTRACT: *The excessive biological sludge production is one of the disadvantages of aerobic process such as SBR. So the problem of excess sludge production along with its treatment , and disposal in aerobic processes in municipal and industrial waste water can be seen in many parts of the world even in our country . to solve the problem of excess sludge production , reducing in by oxidizing some of the sludge by Ozone is a suitable idea , thus reducing the biomass coefficient as well as the sewage sludge disposal. In this study, Two SBR reactors with of 20 liter being controlled by on-line system are used. After providing the steady state in the reactors, along the 8 month research sampling and testing parameters such as COD, MLSS, MLVSS, DO, SOUR, SVI, residual ozone and Yield coefficient were done. The results showed that during the solid retention time of 10 days the kinetic coefficient of Y and* K_d *was 0.58 (mg Biomass / mg COD) and 0.058 (1/day) respectively. At the next stage of research, different concentrations of ozone in one liter of the returned sludge to reactor were used to reduced the excess biological sludge production. The results showed that the 20 mg ozone per gram of MLSS in one liter of the returned sludge to reactor is able to reduce Yield coefficient from 0.58 to 0. 28 (mg Biomass/mg COD), In other words, the biological excess sludge by 52 % .but the soluble COD increased slightly in the effluent and the removal percentage decreased from 92 in blank reactor to 64 in test reactor. While the amount of SVI and SOUR in this consumed ozone concentration reduced 9 mgO2/h.gVSS and 20 ml/g respectively. No sludge was seen in the 25 mg ozone concentration per gram of MLSS in one liter of the returned sludge to reactor.*

KEY WORDS: *SBR reactor, Sludge reduction, Ozone, Oxidation of sludge, Yield coefficient.*

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INTRODUCTION

Removal of organic materials by biological oxidation is a core technology in wastewater treatment process. New cells (sludge), carbon dioxide, soluble microbial products and water are the end products for this process. Activated sludge process has been applied worldwide in municipal and industrial wastewater treatment practice. Daily production of excess sludge from conventional activated sludge process is around 15-100 L/ kg BOD5 removed, in which over 95 % is water [1,2].It is evident that in general purpose of activated sludge process is in the removal of organic pollutants rather in cultivation of excess sludge.

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 five stages as filling, reaction, settling, and effluent and idle [1,2].

The biological sludge excess is as heavy as 1.005, with the solid concentration of totally 0.5 to 1.0 percent which is composed of 70 to 90 percent 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 liters per person in a day [2,3].

McCarty (1966) anticipated a quasi-exponential growth of excess sludge production in USA. In 1984, the excessive sludge to be treated in the European Union countries reached 5.56 millions dry materials [4]. With the expansion of population and industry, the increased excess sludge production is generating a real challenge in the field of environmental engineering technology. So far the regulations of food safety, agriculture and sludge disposal in most countries are being more and more stringent in relation to application of biosolids in agriculture and dumping into the sea. It should be realized that biomass production is an important economic factor because the sludge generated is a secondary waste that must be disposed in an environmentally sound and cost-effective manner. Currently, production of excess sludge from activated sludge process is one of the most serious problems encountered in wastewater aerobic treatment [5,7].

The treatment of the excess sludge may account for 25-65 % of the total plant operation cost [11]. One has been looking for appropriate ways to reuse the excess sludge produced from the activated sludge process [8]. An ideal way to solve sludge-associated problems is to reduce sludge production in the wastewater purification process rather than the post-treatment of the sludge generated.

The ultimate disposal of excess sludge generated from activated sludge processes has been one of the most challenging problems for wastewater treatment utilities. Excess sludge treatment and disposal currently represents a rising challenge for wastewater treatment plants (WWTPs) due to economic, environmental and regulation factors [3]. Sludge production is one the major features of under taken 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 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 [3-5].

There is therefore considerable impetus to explore and develop strategies and technologies for reducing excess sludge production in biological wastewater treatment processes[3,5-7].

1- Endogenous metabolism [5,8,10].

2- Uncoupling metabolism [11-13]

3- Increase of DO in reactor [10,17].

4- Oxic settling - anaerobic (OSA)[16].

5 – Ultrasonic cell disintegration[18].

6- Alkaline heat treatment [9,18].

7- Predation on bacteria [18,24-27].

8- Oxidation of a part of produced sludge is done by such oxidizing materials as chlorine and ozone [15, 18-23].

Ozone is a strong chemical oxidant and has been commonly used in water disinfection process.

Ozonation- assisted sludge reduction process is based on the idea that part of activated sludge is mineralized to carbon dioxide and water, while part of sludge is solubilized to biodegradable organics that can be biologically treated. Many research works have been conducted with respect to the ozonation-assisted sludge reduction process [18-20]. A combined activated sludge process and intermittent ozonation system had been successfully developed [19, 20].

In this combined system, excess sludge withdrawn from a continuous activated sludge system was subject to ozonation, and then returned to the aeration tank. Results showed that the excess sludge production was reduced by 50 % at an ozone dose of 10 mg g^{-1} mixed liquor suspended solids (MLSS) d^{-1} in aeration tank, when the ozone dose was kept as high as 20 mg g^{-1} MLSS d^{-1}, no excess sludge was produced [20, 21]. In the study of *Egemen et al.* (1999), a similar technical approach was used. Ozone is a strong cell lysis agent. When sludge is kept contact with ozone in the ozonation unit, most activated sludge microorganisms would be killed and oxidized to organic substances. There is evidence that more than 50 % of the carbon obtained after ozonation is readily biodegradable [22]. This is reason why those organic substances produced from the sludge ozonation can then be degraded in the subsequent biological treatment. Results from a 10-month full-scale ozonation-activated sludge system loaded with 550 kg BOD d^{-1} showed that no excess sludge was produced, and the accumulation of inorganic solids in the aeration tank is negligible, while effluent total organic carbon was slightly higher than under the conventional activated sludge process [22, 23]. It had been reported that the sludge settleability in term of sludge volumetric index was highly improved as compared to control test without ozonation [23, 25]. Apparently, both operation and capital costs of the ozonation- activated sludge process should be high due to energy required for ozone production. However, economical estimate suggests that the operation costs of the whole process was lower than that of conventional activated sludge process if the costs of sludge dewatering and disposal were taken into account [24]. Ozonation-combined activated sludge process would be a useful technology for reducing excess sludge production and further improving sludge settleability, but there are still some problems associated with this technique. Ozone is not a selective oxidant, it can react with other reducing materials, and this may lower the oxidation efficiency of activated sludge, while refractory organic carbon can be released into the effluent after ozonation. Sometimes, the toxicity of those released refractory organic carbon might pose problem to effluent receptor. It was also found that the initial rate of ozone consumption by sludge was extremely high and reached 30 mg O3 g^{-1} volatile suspended solids (VSS) min^{-1} [25]. On the other hand, it can be easily understood that the effectiveness of ozonation is strongly dependent upon the physical structure of activated sludge and system operation conditions. These make the optimization of ozone dosage and dosing mode much more difficult [23, 25].

MATERIALS AND METHODS

In this research, the two sequencing batch reactors (SBR) used with cylindrical shape tank, type of Plexi glass, inner diameter of 25 cm, 60 cm height, and net volume of 20 liter and treatment capacity of 10 liter per cycle. Figs. 1 and 2 demonstrate the layout and schematic diagram of sequencing batch reactors (SBR).

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

Fulfilling: 3 minutes, aeration: 4 hours, settlement: 105 minutes, and drainage: 12 minutes. In the pilot run, the fulfilling time of the tank reduced to 70 seconds.

Synthetic wastewater characteristics

The synthetic wastewater of pilot prepared with mixing of 40 mg industrial dry and 100 liter of tab water. The characteristic of wastewater in experiments are as below:

COD= 600 mg/liter

BOD5= 420 mg/liter

Nitrogen (as nitrate): 4.7 mg/liter as N

Nitrogen (as organic nitrogen): 30 mg/liter as N

Nitrogen (as TKN): 30.7 mg/liter as N

Phosphor= 10.5 mg/L

Pilot start u

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

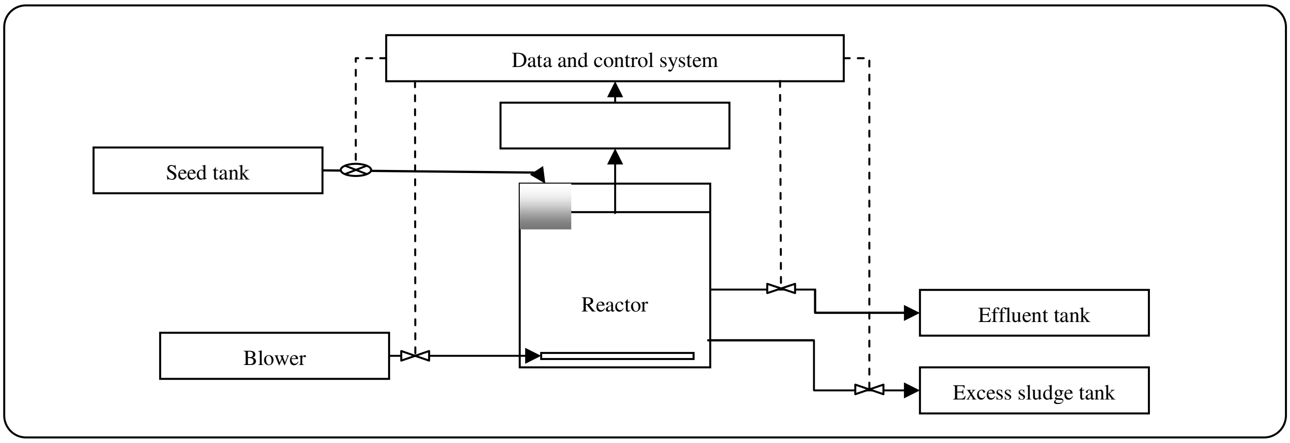

Fig.1: The general view of SBR schematic.

Fig. 2: The general view of SBR schematic.

problems. And, the seed added with volume about 5 liters per SBR with volume of 20 liters 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 ozone and Yielding kinetics tested during 8 months.

The tests performed according to standard methods for the examination of water and wastewater [28].

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 ozone 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. SBR run 3 times by different ozone feed to reactor to reduce of excesses sludge production. Finally, the data gathered and only the average of data reported(*APHA et al.,* 1995).

RESULTS AND DISCUSSION

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, according to Fig. 4 different COD concentrations as to 300 ,400, 600, 800 , wore 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 1: The amount of different COD in 10 days SRT to determine the Y and K_d.

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

It should be noted that in this study, the temperature was maintained by the adjustable aquarium heater at 20 to 22 degrees centigrade 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. 3, K_d=0.056 (1/day), Y=0.58 (mg Biomass/mg COD) during the 10 day cell retention time with out the addition of ozone. In higher ozone 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 ozone to some parts of sludge.

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

where:

dx/dt = the increase rate in biomass concentration or MLSS (mg/>)

ds/ dt = the removal rate of substrate or COD (mg/L)

$$Y = X_0 - X/S_0 - S$$

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).

The biosynthetic co-efficiency rate of biomass (Y) is in the different ozone concentration injected into the reactor of table 2, as the table shows under 8 and 20 mg ozone per gram MLSS in reactor, the values of biomass production are 0.46and 0. 28 mg biomass /mg COD respectively.

As can be seen in table 2, in the state of no- ozone with COD=600 mg/L, the Yield coefficient equals 0.58 mg biomass /mg COD and the removal of COD is 92 %. But by adding ozone to reactor the yield coefficient decreases, in a way that by adding 16 mg ozone per gram of MLSS in reactor, 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 went around 79 % by adding 25 mg of ozone per gram of MLSS into the reactor resulted in no excess sludge, yet the COD removal coefficient was lowered to 42 %. In such amount of ozone, many microorganisms in the reactor turned non-viable and died. The cause of such a low coefficient is that Ozone 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).

Table 2: The effect of added ozone on Y, SVI, SOUR, COD removal and residual 0zone

The value of added ozone to Sludge ($mgO_3/gMLSS$)	Y $\left(\frac{mgBiomass}{mgCOD}\right)$	residual ozone in the end of reaction (mg/l)	COD removal (%)	SVI (ml/g)	SOUR ($mgO_2/h.gVSS$)	Sludge reduction (%)
0	0.58	0	92	90	18	-
1.66	0.61	0	93	92	20	5% (increase)
2.5	0.56	0	91	88	17	3.5
4.2	0.5	0	88	83	14	13.8
8	0.46	0	85	62	11	20.7
12.5	0.41	0.01	83	44	7	29
16	0.33	0.05	79	35	5	43
20	0.28	0.2	64	20	3	52
25	0	0.5	42	0	3	100

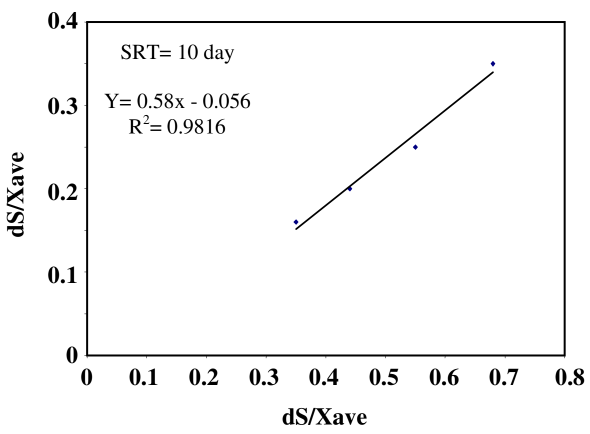

Fig. 3: Determination of Y and k_d in SRT =10 days. Under no-ozone-addition condition.

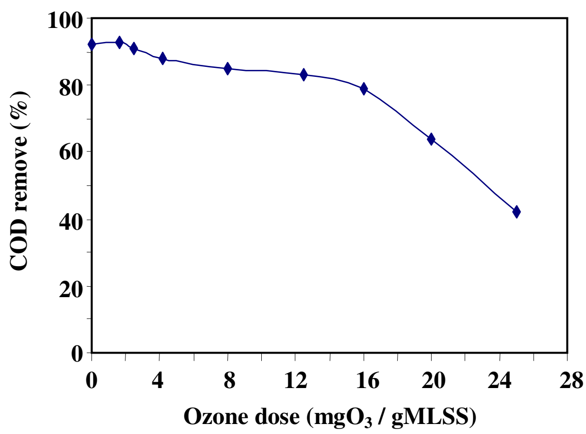

Fig. 4: The effect of ozone does on COD removal efficiency.

The effects of different ozone doses on COD removal co-efficiency

Fig. 4 Shows the effect of different ozone doses into SBR reactor on the COD removal co-efficiency. Despite being effective in controlling filamentous balking and minimizing the excess sludge production, ozone causes the slight soluble COD in crease in effluent. According to Fig. 4 along the increase of ozone, the COD removal co-efficiency decreases , so much so that COD removal co-efficiency reaches less than 64 % in 20 mg ozone dose per gram MLSS in 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.

The effect of different ozone doses on SVI

According to Fig. 5, as the rate of ozone dose addition to reactor the SVI decreases in a way that with the 20 mg ozone dose per gram of MLSS in to reactor, SVI abates to around 20 ml/g the other hand having increase the chlorine doses, the MLVSS/MLSS ratio decreases, thus light increasing the specific weight of sludge.

The effect of different ozone doses on SOUR

According to Fig. 6, along with the increase of doses added to reactor oxygen consumption rate reduces because of the killing of a significant portion of microorganisms therefore the SOUR rate reduces in accordance with each mgr of oxygen in hour per gram of volatile suspended solids. As a result in the ozone doses

Table 3: SOUR and oxygen consumption rate in different conditions.

significance	Oxygen consumption rate	SOUR(mg/h. g VSS)
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 material	low	Less than 12

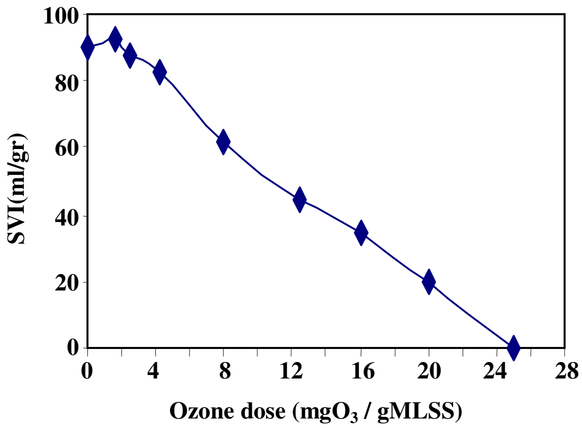

Fig. 5: The effect of ozone does on SVI.

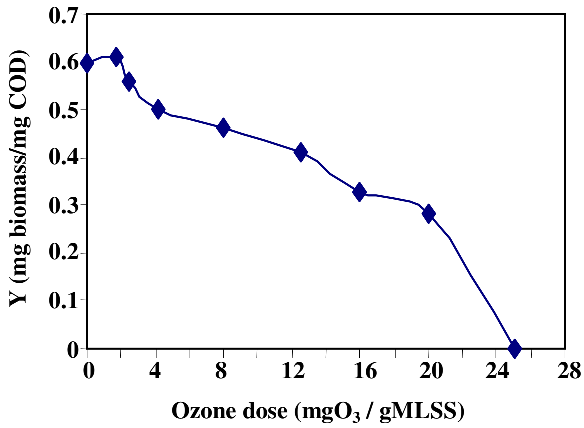

Fig. 7: The effect of Ozone does on Y.

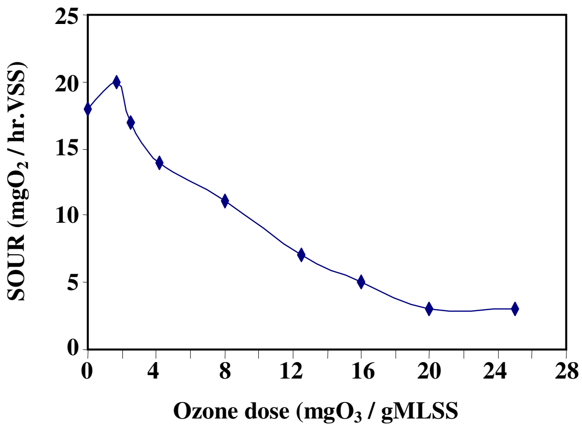

Fig. 6: The effect of Ozone does on SOUR.

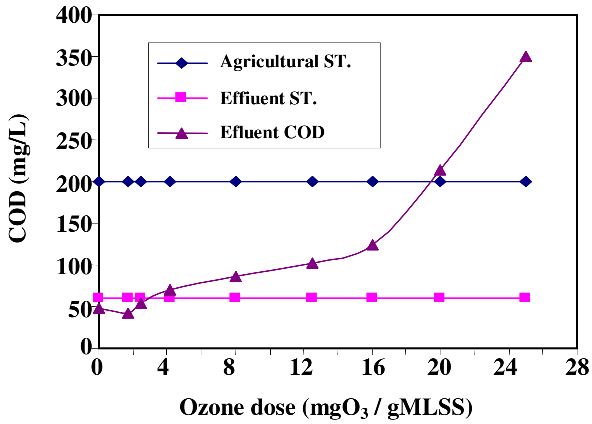

Fig. 8: Compare of Effluent Wastewater COD removal by different ozone dosage with Iran wastewater reuse standard for agricultural reuse.

of 20 mg per gram of MLSS in to SBR reactor SOUR lowered to 3 mg O_2/ h. gr VSS. This happens because of the Ozone’s bring inhibitive (Table 3).

The effect of different ozone doses on Yield coefficient

Fig. 7 shows the effect of different ozone doses into SBR reactor on Yield coefficient. The results s howed that the 20 mg ozone per gram of MLSS in the reactor is able to reduce Y coefficient from 0.58 to 0.28 (mgBiomass/mgCOD), In other words, the biological excess sludge by 52 %. No sludge was seen in the 25 mg ozone concentration per gram of MLSS. In ozone dose more than above mentioned amount (25 mg). Organic matter removal coefficient reduced as a result of the inhibitory effect of chlorine on microorganisms.

Compare of effluent wastewater COD with disposal and reuse standard of ozonated sludge.

The Fig. 8 shows that 10 day cell retention time in just 4.2 mg O_3 / g MLSS of circulated sludge can reach to

Table 4: Literature data for reducing excess sludge production by Ozonation.

Operation condition	Sludge reduction	Effluent quality	References
Full scale: 550 kgBOD/d of industrial waste water, continuous ozonation at 0.05g O_3/gMLSS	100	Increase of COD	Yasui 1994
Full scale: 450 m^3 /d of municipal waste water, continuous ozonation at 0.02g O_3/gMLSS	100	Slightly 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 waste water, intermittent ozonation To sludge in SBR at: 1- 16 mg O_3/gMLSS 2- 20mg O_3/gMLSS 3- - 25mg O_3/gMLSS	43 52 100	Slightly Increase of COD	This study

standard levels. But, 20 mg O_3/ g MLSS of one liter circulated sludge is in compliance with wastewater reuse standard of agricultural uses. And, the higher dosage than this level can not be in compliance with standard levels.

Finally, the use of ozone is considered one of the chemical methods of reducing the production of biological excess sludge. With the high ozone concentration in to 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 20 mg concentration of ozone to per gram of MLSS in to the reactor reduces by 52 percent. In the high concentration of ozone to reactor (25 mg concentration of ozone to per gram of MLSS in to the reactor) no biological excess sludge is produced, but the COD removal percentage in the effluent reduces. Table 4 shows the comparing of results of this study with other performed research in the reduction of excess sludge production with ozonation.

CONCLUSIONS

Ozone is one of the excess biological sludge reduction methods which can reduces excess biological sludge, considerably.

The experiment demonstrated that

1- MLSS concentration increase a little after initially breakthrough due to feed ozone. COD removal efficiency reaches to 52 % at 20 mg/L ozone per gram MLSS. Also, MLSS concentration reduced considerably.

2- The amount of SVI and SOUR in this consumed ozone concentration (20 mg O_3/ g MLSS of one liter circulated sludge) reduced 9 mgO_2/h.g VSS and 20 ml/g respectively.

3- Biomass production rate per gram COD (Yield coefficient) in 10 day cell retention time in without ozone dosage reach to 0.58 produced biomass.

But, Y rate decreases with ozone dosage increment to part of sludge. And, 10 day cell retention time in just 4.2 mg O_3 / g MLSS of circulated sludge can reach to standard levels.

4- In the high concentration of ozone to sludge, (25 mg concentration of ozone to per gram of MLSS in one liter of return sludge to the reactor) no biological excess sludge is produced, but the COD removal percentage in the effluent reduces.

5- Consequently, ozonation-combined activated sludge process would be a useful technology for reducing excess sludge production and further improving sludge settleability. Future research should be focused on optimization of ozone dosage and dosing mode.

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