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Full Length Research Paper

Effect of various ORP on excess sludge reduction in oxic-settling-anaerobic batch-activated sludge

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Studies were carried out in two SBR reactors, which were controlled online. After presenting a stable situation in the reactors, during 24 months of the study, sampling and examining of COD, MLSS, MLVSS, pH, DO, SOUR, SVI, ORP and biomass yield (Y) were implemented. The results showed that maximum COD removal efficiency (95%) wad achieved in 10 days retention time and average biomass yield (Y) and K_d were 0.58 (mg biomass/mg COD) and 0.058 (l/day) respectively. After 7 h of the sludge retention time at ORP of -238 mV, the biomass yield (Y) decreased from 0.62 to 0.25 mg biomass/mg COD. Consequently, the excess sludge decreases up to 60%. In this method, the amount of effluent COD is less than the amount of environmental standards of Iran for discharge into surface water and irrigation uses. On the other hand, at the ORP of -238 mV, the amount of SOUR and SVI reached 22 mgO_2/h.g VSS and 40 ml/g respectively.

Key words: Biomass yield, excess sludge reduction, ORP, OSA, sequencing batch reactor.

INTRODUCTION

The activated sludge process is a primary method for treating municipal and industrial wastewater. Although it generates large amount of excess sludge as a byproduct, its efficiency in removal of organic matter is high (Chon et al., 2011; Takdastan et al., 2009). Ultimate disposal of excess sludge always has been and always will be one of the most expensive problems faced by wastewater treatment plants, for example, the treatment of the excess sludge may account for even in some cases 65% of the total plant operation cost. So in recent years, extra focus has been given to the minimization of waste sludge in wastewater treatment process (Guowei et al., 2007; Perez-Elvira et al., 2006; Takdastan et al., 2009; Tokumura et al., 2007; Xie et al., 2010; Yan et al., 2008).

So far several techniques to reduce the sludge production have been presented in literature. The main strategies, as ozonation, sonification, and thermal or mechanical device, determine the disintegration of a fraction of the recycle sludge flow rate using the increase of the biomass lysis (Prorot et al., 2011; Yongqing et al., 2011). The treated flow, back to the activated sludge tank, supplies an extra carbonic load to the process and is in need of oxidation. As a fraction of carbon prepared by the biomass is lost in the atmosphere as CO_2 during the decay of the cell, the repeated metabolism of the same carbon will decrease the overall biomass, which growth is named “cryptic” (Khursheed and Kazmi, 2011). These methods have proved reliability; however they are not low cost technologies, considering the oxygen and the energy supply. Instead of trying for the cryptic growth, it is possible to act on the mechanisms which biomass depletes and uses substrate. With uncoupling metabolism, when the cells dissipate part of their

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intracellular energy to cycles that do not turn into cell growth, a reduction of the growth yield can be achieved. There are various studies about the use of biochemical uncouplers (that is, tetrachlorosalicilanilide, para-nitrophenols, and dinitrophenols) in the activated sludge process; the use of them could determine a possible harmfulness to the environment and poor sludge settleability (Liu et al., 2003; Wei et al., 2003; Ye et al., 2003). As an alternative method, the addition of an anaerobic step (kept on ORP equal to -250 mV) on the recycle sludge flow was studied (Chudoba et al., 1991, 1992). Applying a high organic load, the modified activated sludge, called OSA, attained a Y_{obs} of 0.24 kgTSS/$kgCOD_{loaded}$, lower than that one of the conventional process (0.38 kgTSS/$kgCOD_{loaded}$). In a later article (Saby et al., 2003), the process was assessed for nine months in a continuous bench scale system. During this experimental period, a decrement of the ORP level in the treatment tank (from +100 to -250 mV) determined a lower Y_{obs}. Moreover, the role of the HRT of the treatment rank was pointed out. In fact, at the same ORP level (-250 mV), a Y_{obs} reduction of 30% was achieved by Saby et al. (2003) compared with the results found by Chudoba in 1992. The decrement of Y_{obs} from 0.24 kgTSS/$kgCOD_{loaded}$ (Chudoba et al., 1992) to 0.18 kgTSS/$kgCOD_{loaded}$ (Saby et al., 2003) was obtained using a higher HRT (from 3 to 10.4 h).

Moreover, Chen and Liu (1999) identified the key of the sludge reduction in the OSA system with the alternation of the feasting and fasting phase. The coupling of feasting condition, provided in the oxidation unit (presence of nutrients and aerobic conditions), and of the fasting one, applied in the treatment tank (absence of nutrients and anoxic or anaerobic conditions), stimulates an uncoupling metabolism. Afterwards the Y_{obs} in batch tests on OSA sludge samples, after a fasting/feasting treatment, were evaluated (Chen et al., 2001; Foladori et al., 2010). Non-reduction was found and the OSA process sludge diminution was related with the enhancement of the sludge decay (Chen et al., 2003). Notwithstanding, in a recent work (Jia et al., 2012; Troiani et al., 2011; Ye and Ying, 2010), the uncoupling metabolism is still regarded as a possible reason. Therefore, this study was conducted to investigate and analyze the influence of various oxidation reduction potential in oxic-settling anaerobic process for biological excess sludge reduction on the activated sludge in a batch culture process. To reach that, reverse activated sludge of Ekbatan wastewater treatment plant was used as seed in sequencing batch reactor pilot reactors and synthetic wastewater with COD of 600 mg/L which was added to the reactor. Experiments were carried out in pilot scale and planning system operation was done by software. After providing stable conditions in the reactors during 12 months of study, sampling and examining parameters such as COD, MLSS, MLVSS and dried sludge solids percentage, SVI, F/M and finally biomass yield were measured.

MATERIALS AND METHODS

Collection of samples and wastewater characteristics

Two non-continuous cylinder shaped reactors made of Plexiglas was used for this study with 25 cm internal diameter, 60 cm height, 20 L working volume and 10 L treatment capacity in each cycle. Planning system operation was done by software. The software could control and keep all operations of the system. Pilot sewage input was made of 40 g industrial milk powder and 100 L drinking water. In this study, quality profile of the synthetic wastewater is as follow:

COD = 600 mg/L;
BOD_5 = 420 mg/L;
Nitrous nitrogen concentration = 4.7 mg/L nitrogen;
Ammoniac nitrogen concentration = 0.7 mg/L;
Organic nitrogen concentration = 30 mg/L;
Kejeldal nitrogen concentration = 30.7 mg/L;
Phosphorus concentration = 10.5 mg/L.

Pilot start up

For setting up and starting up the SBR, reverse activated sludge of Ekbatan wastewater treatment plant was used as seed - which did not have any bulking, foaming and pin-point flock - in about 2 L for each SBR pilot reactors with total volume of 20 L and synthetic wastewater with COD of 600±20 mg/L was added to the reactor. According to the type and characteristics of the used wastewater in the present work, time duration was the same in both the reactors. Filling ends were performed in 3 min, aeration in 4 h, sedimentation in 1 h and 45 min and draining in 12 min and in fact, the required time for filling was shorter and it approximately took place in 1 min and 10 seconds.

Aeration and reaction took place approximately 2 weeks for flock or biomass formation in such a way that only the reaction was done, but nutrients were added to the reactor daily. After two weeks, the pilot system of SBR was launched by 5 cycles which are filling, reaction, discharge, sludge discharge and rest. COD, SS, pH of the effluent in different turns were very close, which showed that reactor startup came to its end. After having stable conditions in the reactors during 12 months of study, sampling and testing parameters such as COD, MLSS, MLVSS and dried sludge solids percentage, SVI, F/M and finally Y were determined. Sampling methods and examinations were all under guidance of Standard Methods for examination of water and wastewater.

Changing conditions

In order for the system to adapt with the new situation, at least 2 weeks (42 cycles) for changing the sludge age

Table 1. The effect of sludge retention time on pH and biomass yield at various ORP.

Sludge retention time in holding tank (h)	ORP (mV)	pH	$Y \frac{mgBiomas}{mgCOD}$	Sludge reduction %
0	-30	6.2	0.6	-
1	-80	6.6	0.56	6.7
2	-130	6.8	0.52	13.4
3	-160	6.4	0.48	2
4	-190	6.8	0.41	31.7
5	-210	6.6	0.33	45
6	-230	6.8	0.31	48.3
7	-238	6.8	0.256	58.3
8	-246	7.1	0.26	56.7

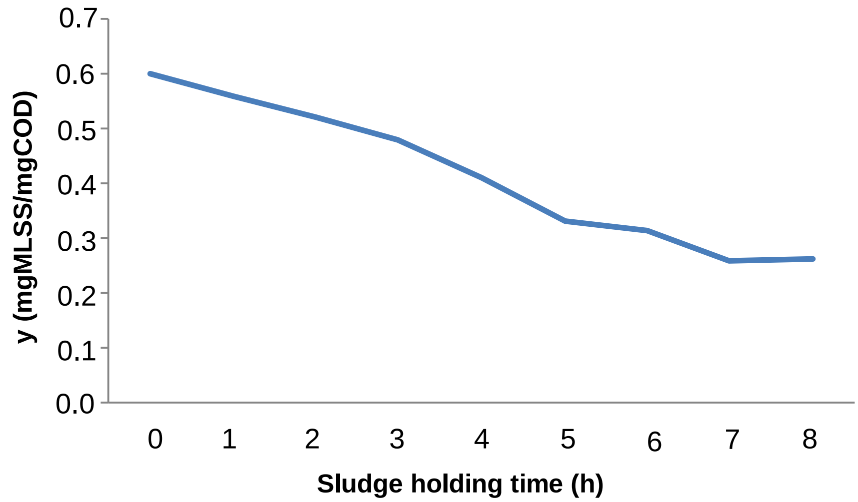

Figure 1. The effect of various ORP on biomass yield at different sludge holding times.

and 1 week (21 cycle) for changing oxidation-reduction potential in sludge storage tank were considered. It lasted 3 days adaptation for changing in influent COD, to determine kinetic coefficient (k_d,Y) in various sludge retention times (5, 10, 15, 20, 25 days). All the measurements were carried out after stabilization. The SBR system worked very well without any bulking and foaming problems in 10 days retention time, so it was selected as optimum retention time and all the experiments was carried out in this time. Concentration of suspended solids in the reactor and COD of effluent were determined as stabilization indicators. All the samples were examined in three times in order to be more precise and accurate.

RESULTS AND DISCUSSION

Determining sludge observed yield in various ORP

In order to survey the effectiveness of uncoupling metabolism of anoxic and anaerobic phases of sludge on decreasing the biomass yield production, the sludge maintained in the reactor approximately 1 to 8 h before the reaction phase and with different oxidation and reduction potentials.

The observed sludge yield in various sludge retention times at ORP of -30/-246 mV are mentioned in Table 1 and Figure 1. As it is shown, with increasing sludge retention time, observed yield was decreased.

As in the 8 h retention time in anaerobic condition (ORP of -246 mV), biomass yield decreased to 0.26 mg biomass/mg COD. When the sludge was kept in the anaerobic reactor, without external substrate and at low ORP levels, a decrease of ATP content in sludge occurs. Optimal conditions for the formation of new ATP (oxygen and availability of substrate) are discarded when the sludge returns to the activated sludge stage. This cyclic alternation of ATP content in sludge uncouples catabolism and anabolism, which causes a decrease in biomass yield favoring sludge reduction (Foladori et al.,

Table 2. Literature studies of OSA techniques for reducing excess sludge.

Operating condition	$Y\ \frac{(mgBiomas)}{mg\ COD}$	Effluent quality	References
Pilot scale OSA system, COD = 300mg/l			
1. Conventional activated sludge	0.4	Good	Saby et al. (2003)
2. OSA system at ORP = +100mV	0.32	Excellent	
3. OSA system at ORP = -100mV	0.22	Excellent	
4. OSA system at ORP = -250mV	0.18	Excellent	
Pilot scale OSA system, COD = 365mg/l			
1. Conventional activated sludge	0.53	Good	Wang (2008)
2. OSA system ORP = -250mV	0.38	Excellent	
Pilot scale OSA system under anoxic-anaerobic zone, COD = 600mg/l			
1. At ORP = -30mV	0.6	Good	Current research
2. At ORP = -80mV	0.56	Good	
3. At ORP = -190mV	0.41	Good	
4. At ORP = -230mV	0.31	Excellent	
5. At ORP = -246mV	0.26	Excellent	

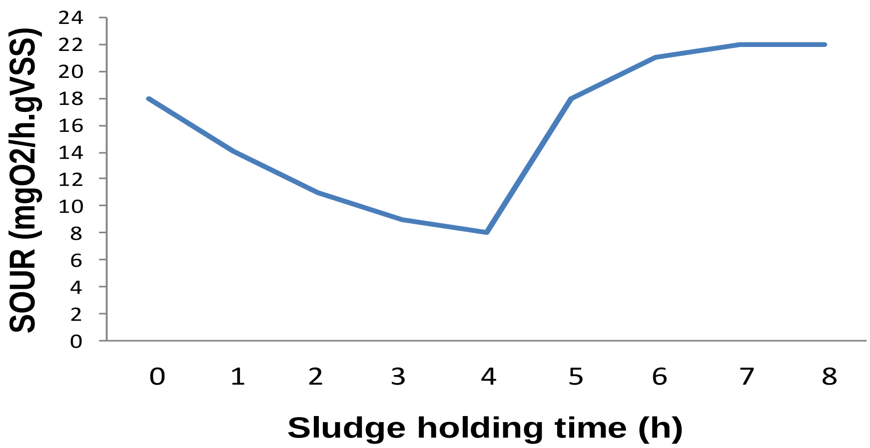

Figure 2. The impact of various ORP on SOUR at different sludge holding time.

2010).

These research findings in excess sludge reduction at low ORP values are compared with those of some other researchers according to Table 2. These results are in line with Saby et al. (2003) and Wang et al. (2008). The observed sludge yield in the OSA system was 0.18-0.32 kgTSS/kg COD $_{removed}$ compared to 0.4 kg TSS/kg COD $_{removed}$ in the conventional activated sludge process (Saby et al., 2003).

The impact of various ORP on SVI and SOUR

Batch respirometric tests for definition of SVI and endogenous SOUR were carried out. The SOUR changes in various sludge retention times (at ORP ranges of-30/-246 mV) are shown in Figure 2. As it is shown, SOUR was decreased with increasing sludge retention time as in 4 h operation time at ORP of –190 mV, SOUR decreased to 8 mgO_2/hr/gr VSS.

SOUR activity suddenly increases when microorganisms absorbed organic substrate and stores them as energy in the sludge aerobic zone, while SOUR decreased under anaerobic condition in the absence of organic substrate. As a matter of fact, SOUR is a reaction of aerobic microorganisms activity which indicates microorganisms' capability in oxidation of organic matters. SOUR changes in oxic-anaerobic cycle are due to bacteria activity changing alternately, thereby creating

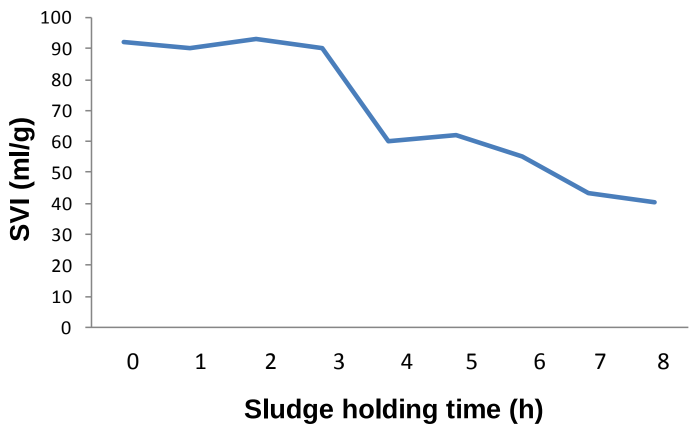

Figure 3. The impact of various ORP on SVI at different sludge holding time.

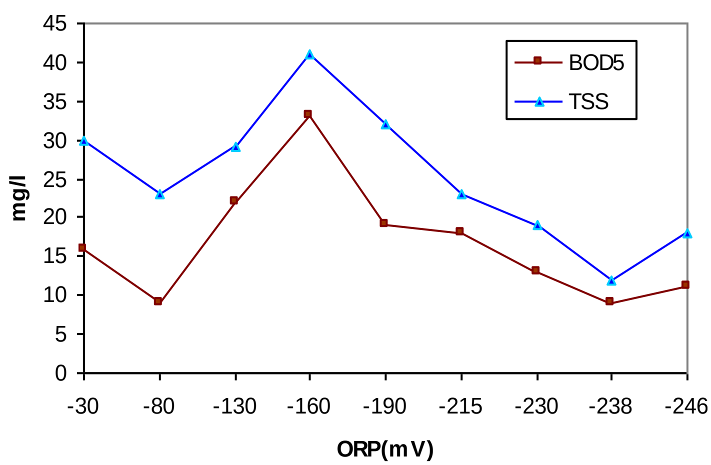

Figure 4. BOD_5 and TSS in the effluent at various ORP.

under oxic-anaerobic condition a result of metabolic uncoupling.

Figure 3 summarizes the SVI variety in diverse operating time at various ORP. As indicated, with increasing sludge retention time, SVI is decreased as it decreased from 92 to 40 ml/g at 8 h sludge retention time.

The SVI value of the sludge in the OSA process was much lower than that observed in the conventional process, that is, the OSA process could improve the settleability of the activated sludge process. Ramakrishna applied the OSA system in industrial scale and indicated that it prepares a promising technique for efficiently reducing the sludge production by improving the stability of process operation (Ramakrishna and Viraraghavan, 2005). These may be related to the release of intracellular polymers under anoxic condition since they can act as flock bridging agents to improve sludge settleability (Saby et al., 2003).

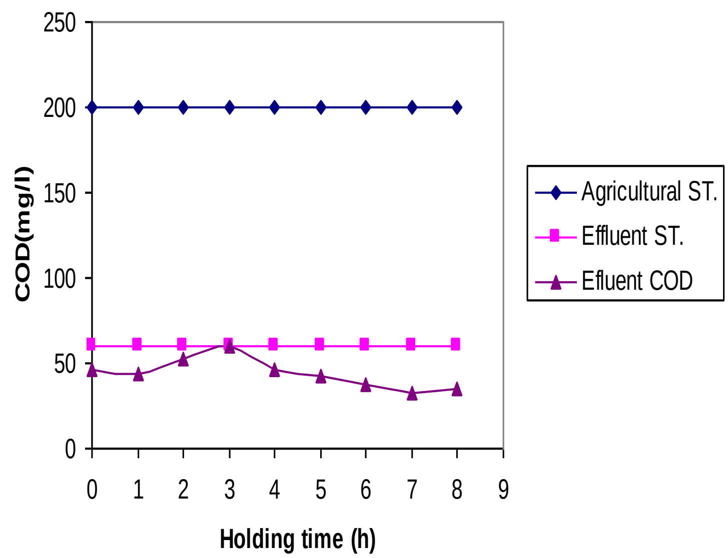

Figure 5. The comparison of effluent COD in the reactor with standards at various ORP.

BOD and TSS in the effluent

Figure 4 shows the variations of BOD_5 and TSS concentrations in different ORP values. It was found, with increasing sludge retention time of 3 h that at ORP of –160 mV, the effluent BOD_5 and TSS concentration increased, as at ORP of –160 mV, the effluent BOD_5 and TSS was 33 and 41 mg/l respectively. Under anaerobic condition when sludge retention time increased more, the BOD_5 and TSS concentration in the effluent decreased as at ORP of –230 mV, BOD_5 and TSS concentration measured 13 and 19 mg/l respectively. In other words, the OSA system is able to improve the effluent quality. An explanation is that when sludge is exposed in a low ORP environment in the anoxic tank, the sludge may be starved under a stressful condition, which in turn increases its substrate removal ability in the following aerobic environment with the presence of adequate food in the aeration tank to which the anoxically treated sludge returns. (Troiani et al., 2011)

The comparison of the effluent COD with wastewater disposal and reuse standards in OSA system

Figure 5 shows the comparison of effluent wastewater COD with Iran wastewater disposal standards and agriculture reuse standard in oxic-settling-anoxic condition. As it is shown, in 10 days cellular retention time under oxic-anoxic condition at various ORP levels, effluent COD is below wastewater disposal standards. Results indicated that adding anaerobic tank in SBR system resulted in improving COD removal efficiency, thus enhancing the effluent quality and sludge settleability.

Conclusion

Pilot scale study managed in batch condition showed as the application of an ORP range favorably produced a drop off of biomass yield and excess sludge. With increasing sludge retention time, biomass yield decreased as in 8 h retention time; at ORP of –246 mV biomass yield decreased to 0.26 gr biomass/g substrate, so 56.7% sludge reduction was observed. The experimental results showed considerable SVI reduction and sludge settleability with increasing sludge retention time. BOD_5 and TSS concentration suddenly increased at ORP of –160 mV at first 3 h and then decreased with increase in sludge retention time under anaerobic condition at ORP of –230mV. Under anoxic- anaerobic condition (various ORP levels), effluent COD was below Iran wastewater disposal standards and agriculture reuse standard. Anaerobic zone application in SBR system improved COD removal efficiency and so enhanced effluent quality and sludge settleability.

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