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Study of Biological Excess Sludge Reduction in Sequencing Batch Reactor by Heating the Reactor

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The municipal wastewater sludge has been identified as a hazardous waste. Thus stabilization and sanitation of sludge prior to discharge into the environment and its reuse in accordance with environmental laws are inevitable. An ideal way to solve sludge-associated problems is reducing sludge formation in the wastewater purification process rather than the post-treatment of the generated sludge. Most biological wastewater treatment processes are temperature sensitive; therefore increasing process temperature is effective for reducing sludge production. Main objective of this research is to reduce sludge production during wastewater treatment process which can contribute to reduction in excess sludge treatment and disposal challenges in wastewater treatment plants due to economic, environmental and regulation factors. In this research, two sequencing batch reactors with the capacity of 20 L, controlled by on-line system were used. Long term (6 months) continuous experiments were conducted to identify the influence of controlled up-shifting of temperature from 40 to 60 °C within the reactor during the reaction phase on reduction of biological excess sludge. Once steady state condition established in the reactors, samples were taken and analyzed for COD, BOD_5, TSS, MLSS, SOUR, SVI and Y coefficient. Results showed that when temperature increased from 23 to 45 °C, during the solid retention time of 10 days, the kinetic yield coefficient decreased from 0.63 to 0.46. In the other word, the excess sludge was reduced by *ca.* 27 %. While, the soluble COD increased slightly in the effluent and the removal percentage decreased from 89 in the control reactor to 63 in the test reactor. The amount of SVI and SOUR in the mentioned temperature reduced to 50 mL/g and 12 mgO_2/h gVSS, respectively. At 60 °C, no sludge was observed, while effluent SCOD and turbidity increased considerably and exceeded the APHA wastewater disposal standard.

Key Words: Sequencing batch reactor, Excess sludge reduction, Temperature, Yield coefficient.

INTRODUCTION

One of the aerobic processes in waste water treatment is sequencing batch reactor (SBR). In recent years SBR has been widely used to treat industrial and municipal wastewater because of its low cost and suitable efficiency in pollutant removal. The process includes such five stages as filling, reaction, settling, effluent and idle[1,2].

Wastewater treatment always consists of two separated parts, effluent and sludge among which the treated effluents can be discharged in to the environment. The produced sludge needs to be treated before being disposed or reused[3]. The raw sludge contains a variety of pathogenic microorganisms such as bacteria, virus, protozoa and parasites. The amount of these organisms is much more than the wastewater[4].

Excess sludge treatment and disposal currently represents a rising challenge for wastewater treatment plants (WWTPs) due to economic, environmental and regulation factors[5].

Sludge production is one the major features of under taken in the biological treatment of wastewater. About 40 to 60 % of the investments 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[5,6].

At least four technical approaches have been seriously considered with respect to excess sludge handling. One is to convert the excess sludge to value-added construction materials or activated carbon[7]. Second is to recover useful resources from sludge, *e.g.* production of fuel byproducts through sludge melting or sludge pyrolysis and extraction of useful chemicals from sludge and so on[8]. Third is to innovatively manage existing outlets of sludge disposal[9], while the last approach is to reduce sludge production from the wastewater treatment process rather than the post-treatment or disposal of the sludge generated. Among these four approaches, the development of innovative technology for reducing excess sludge production is essential.

Heat-treatment is considered to be simple to operate compared to other treatments such as ozonation, chlorination, capable of being applied separately or being combined with other methods, such as alkaline or acid treatment[10], membrane methods[5]. However, the biological response of the sludge matrix induced by heat-treatment was poorly understood[11].

Most biological wastewater treatment processes are temperature sensitive and thus increasing process temperature is effective for reducing sludge production. Low temperature operation can lead to increase of sludge production, *i.e.* the sludge production at 8 °C in the activated sludge process was increased by *ca.* 12-20 % compared with the 20 °C temperature condition[12].

A side-stream membrane bioreactor (MBR) treating synthetic wastewater by *Pseudomonas fluorescent*, coupled with a continuous sludge thermal treatment system, was operated for reducing excess sludge production. About 60 % of sludge reduction achieved when the returned sludge passed through a thermal treatment loop (90°C for 3 h)[5].

The reduction of excess sludge by heat-treatment is induced by sludge lysis and further cryptic growth (lysis-cryptic growth)[10]. In the lysis-cryptic growth, sludge reduction is achieved because some portions of lysates are consumed for the catabolism and finally emitted as CO_2. Consequently, the microbial community succession in the sludge should occur during heat-treatment. With the development of molecular microbiological techniques, denaturing gradient gel electrophoresis (DGGE) analysis of PCR-amplified 16S rDNA has been used as a useful tool to analyze the diversity of a microbial community[13].

High temperatures can also be combined with acid or alkaline treatment to reduce excess sludge. Different cell lysis techniques (thermal, combination of thermal and alkaline or acid) were then compared with break *Alcaligenes eutrophus* and wasted activated sludge[14,15]. Their results showed that alkaline treatment by NaOH addition combined with thermal treatment (pH 10, 60 °C for 20 min) was the most efficient process to induce cell lysis and produce biodegradable lysates. The coupling of this lysis system to a biological wastewater treatment bioreactor allowed a 37 % reduction in the excess sludge production compared with the CAS process.

In this study, the reactor was heated during the reaction time from 40 to 60 °C in order to reduce biological excess sludge.

EXPERIMENTAL

Reactor and synthetic wastewater characteristics: The reactors consisted of two cylindrical sequencing batch reactor made from poly glass with efficient volume of 20 L (25 cm inner diameter and 60 cm height). The treatment capacity of reactors was 10 L in each cycle.

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

Since the control of different operation stages is highly dependent on time in the sequencing batch reactor system, a computerized system along with its auxiliary parts were used. the different stages were controlled and the concentrations of the dissolved oxygen, temperature and pH were measured by the mentioned system. It should be noted that the amount of dissolved oxygen was kept between 1.5 and 2 mg/h.

TABLE-1
SEQUENCE OF OPERATION TIME IN SEQUENCING BATCH REACTOR

Stage	Duration (min)
Fulfilling	3
Aeration	4
Settlement	105
Drainage	12
Idle	2

Fig. 1 demonstrates the schematic diagram of the used sequencing batch reactor. Detailed operational conditions are presented in Table-2.

TABLE-2
SUMMARY OF THE OPERATIONAL CONDITIONS

	Reactor 1 (control)	Reactor 2 (test)
Working volume (L)	10	10
SRT (day)	10	10
Sludge temperature (ºC)	23*	40, 45, 50, 60
Influent COD (mg/L)	500	500
Influent BOD_5 (mg/L)	350	350
Nitrogen (as TKN) (mg/L)	23.5	23.5
Phosphor (mg/L)	7.1	7.1

*Wastewater temperature.

Pilot start up: Initially, seed was provided from the returned activated sludge unit of Ikbatan's wastewater treatment plant (Tehran). To operate the sequencing batch reactor with the capacity of 20 L, *ca.* 4 L of the sludge were used in each reactor. The synthetic wastewater was added to fill up the reactors.

Aeration was performed for *ca.* 2 weeks to form the flocs. After this stage, sequencing batch reactor started up with 5 cycles *i.e.* fulfilling, reaction, wastewater drainage, sludge drainage and idle. One thermostat was installed to heat the reactor during reaction stage. After heating the reactor for 4 h; (during reaction phase) the parameters of COD, SS and pH of wastewater were measured. After 2 weeks, effluent COD data closed to a constant value which demonstrates the steady state condition has been established.After reaching the steady state situation, COD, BOD_5, MLSS, TSS, SVI, SOUR and yielding kinetics were continuously determined for 6 months. The tests were performed according to the standard methods for the examination of water and wastewater[16].

Variable situation: Due to the changes of sludge temperature, at least 2 weeks were considered for the system to be adapted with the new condition. The suspended solid concentration in sequencing batch reactor and effluent wastewater COD were considered as indicators of the steady state condition. According to standard methods for water and wastewater examination, this process was repeated three times, where the results were obtained *via* averaging them. The precision of the results were about 96.5 %[16].

Figs. 1 and 2 show the schematic diagram of the used sequencing batch reactor and its layout, respectively.

RESULTS AND DISCUSSION

Influence of temperature on sludge yield coefficient: During the applied cell retention time (10 days), the amount

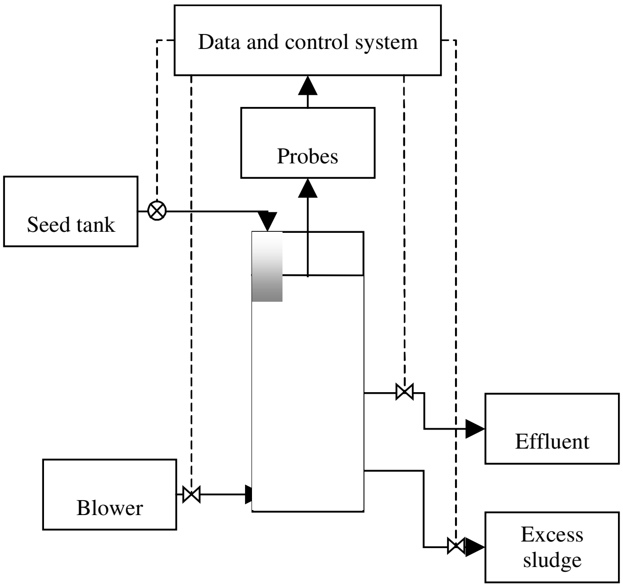

Fig. 1. Schematic diagram of sequence batch reactor

Fig. 2. General view of sequence batch reactor layout

of yield coefficient was 0.63 mg biomass/mg COD at the wastewater temperature. Biomass co-efficiency production during yield operation was calculated by the following equation:

$$Y = \frac{(X_0 - X)}{(S_0 - S)} \quad (1)$$

where: S and S_0 are respectively the primary and ultimate substrate concentrations (mg/L) and X and X_0 are respectively the primary and ultimate biomass concentrations (mg/L)[2,17].

The biosynthetic coefficient rate of biomass (Y) with respect to different temperatures are shown in Table-3. It can be seen in Table-3 that the values of biomass production are 0.46 and 0. 37 mg biomass/mg COD in temperatures of 45 and 50 °C, respectively.

TABLE-3
INFLUENCE OF TEMPERATURE ON Y, SVI, SOUR, COD REMOVAL AND DS

Sludge temp. (°C)	Y $\frac{\text{mg Biomass}}{\text{mg COD}}$	COD removal (%)	SVI (mL/g)	SOUR (mgO_2/h gVSS)	DS (%)	Sludge reduction (%)
23*	0.63	90	95	21	1.1	-
40	0.56	85	85	18	1.2	10.7
45	0.46	63	50	12	2	26.8
50	0.37	43	30	6	3.3	41.8
60	-	0	0	4	0	100

*Wastewater temperature.

As can be seen in Fig. 2, at the wastewater temperature the yield coefficient equals to 0.63 mg biomass/mg COD. By increasing the temperature up to 45 °C in the reactor, the yield coefficient decreased to 0.46 mg biomass/mg COD and further increment of the temperature up to 50 °C, reduced the yield coefficient to 0.37 mg biomass/mg COD due to bacterial cell lysis and microorganism death in the reactor (except for limited number of slime microorganisms which were tolerant to the applied temperatures).

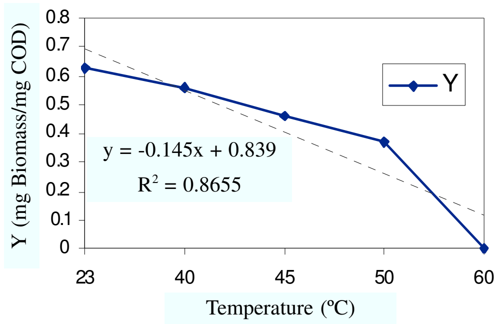

Fig. 3. Effect of temperature on yield coefficient

Influence of temperature on COD removal: Figs. 4 and 5 show the effect of different temperatures on the COD and BOD_5 of the effluent. The increase of SCOD and BOD_5 values in the treated effluents as a result of temperature increment may be attributed to the solubilization of extra-cellular polymeric substance (EPS) and decreased sludge substrate removal capacity[18]. According to Figs. 4 and 5, massive cell lysis occurred when temperature shifted from 23 to 50 °C and then 60 °C.

By increasing temperature up to 45 °C, effluent COD and BOD_5 were increased and reached to 183 and 141 mg/L, respectively. The soluble COD rate increased dramatically in the effluent since heating the reactor to relatively high temperatures (≥ 45 °C) causes cell inactivation and kills a lot of heterotrophic microorganisms.

The protozoa living above 45 °C were mainly small free-swimming ciliates and flagellates, but at 50 °C most of them seemed inactive/dead and a significant amount of protozoan-metazoan debris were observed, thus turbidity in effluent was increased.

Sagastume[18] found that increasing the temperature from 30 to 45°C in activated sludge system, decreased the SCOD removal efficiency by 20 %.

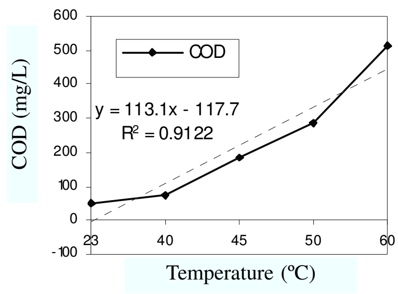

Fig. 4. Influence of temperature on effluent COD

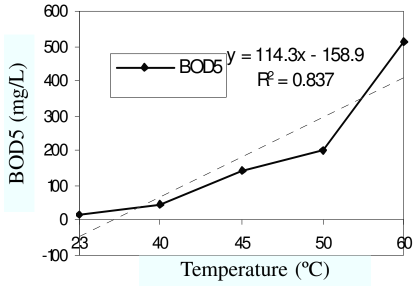

Fig. 5. Influence of temperature on effluent BOD_5

Influence of temperature on SVI: According to Fig. 6, as the temperature increased from 23 to 60 °C, the SVI decreased. For example, at the temperature of 50 °C, SVI abated to *ca.* 30 mL/g. On the other hand having increased temperature, the MLVSS/MLSS ratio decreased, thus slightly increased the specific weight of sludge.

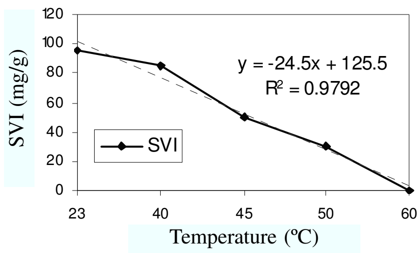

Fig. 6. Effect of temperature on SVI

Influence of temperature on specific oxygen uptake rate (SOUR): There is uncertainty in the relationship between specific oxygen uptake rate (SOURs) and temperature. Barr *et al.*[19] postulated that SOURs may decrease with increasing temperature and that SOURs at high SRTs may be high due to endogenous respiration.

According to Fig. 7, along with the increase of temperature from 23 to 60 °C, oxygen consumption rate decreased due to killing significant portion of microorganisms therefore the SOUR rate was reduced. Specific oxygen uptake rate was lowered to 4 mg O_2/h g VSS at 60 °C due to the temperature's sublethal metabolic inhibition (Table-4). Table-4 shows the SOUR and oxygen consumption rate in different conditions.

Comparison of effluent COD with wastewater disposal and reuse standards: Observed effluent COD was compared with wastewater disposal standard as well as agricultural reuse standard of Iran at different temperatures as shown in Fig. 8.

Effluent COD exceeded wastewater disposal standard of Iran when temperature was increased from 40 to 60 °C. However at 45 °C it met the agricultural reuse standard of Iran.

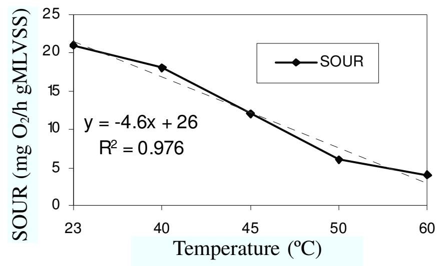

Fig. 7. Effect of temperature on SOUR

TABLE-4
SOUR AND OXYGEN CONSUMPTION RATE IN DIFFERENT CONDITIONS [Ref. 18]

SOUR (mg/h g VSS)	Oxygen consumption rate	Significance
More than 20	High	There is insufficient amount of solids in reactor for BOD load
12-20	Normal	BOD removal is good and the sludge sedimentation is acceptable
Less than 12	Low	There is high amount of solids in reactor or existence of toxic material

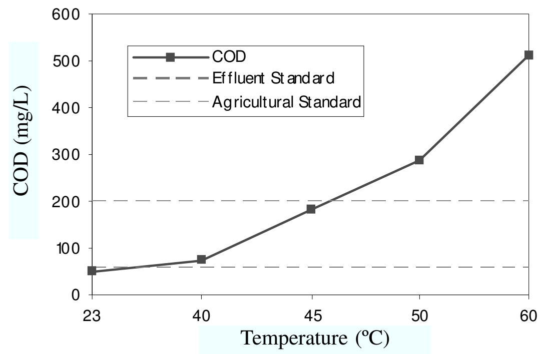

Fig. 8. Comparison of effluent COD removals with Iran wastewater disposal and agricultural reuse standards at different temperatures

Table-5 shows the comparison between the obtained results and other thermal techniques apply for sludge reduction.

TABLE-5
LITERATURE DATA OF THERMAL TECHNIQUES FOR REDUCTION OF SLUDGE PRODUCTION

Operation condition	Sludge reduction (%)	Ref.
Urban wastewater, 65 °C, 48 h	80	20
Thermal or thermo-chemical treatment lab scale (90 °C, 3 h), membrane bioreactor, synthetic wastewater	60	5
Lab scale (60 °C for 20 min, pH = 10), synthetic waste water	37	15
Pilot plant scale, synthetic wastewater, temperature up-shifting in the reactor, (40 to 60 °C), SBR		Present study
1. Temperature up-shifting to 45 °C	27	
2. Temperature up-shifting to 50 °C	42	
3. Temperature up-shifting to 60 °C	100	

Conclusion

Heat-treatment is considered to be simple to operate compared with other treatments techniques such as ozonation and chlorination.

The current research demonstrated that:

(1) By increasing the reactor temperature up to 45 °C, the COD removal percentage decreased and reached to *ca.* 60 % due to solubilization of extra-cellular polymeric substance (EPS) and microbial lysis.

(2) SOUR and SVI indicators at 45 °C were reduced to 12 mgO_2/h gVSS and 50 mL/g, respectively.

(3) At the wastewater temperature, the yield coefficient was 0.63 mg biomass/mgCOD. Increasing the temperature up to 45 °C decreased the yield coefficient to 0.46 due to sludge bacterial cell lysis and death of many microorganisms in the reactor.

(4) At high temperatures, (≥ 60 °C) no biological excess sludge was produced, but the effluent COD was increase and wastewater reuse standard was not met.

(5) The main disadvantage of this method is increasing of effluent COD and turbidity; however, at controlled temperatures, the wastewater met effluent or agricultural reuse standards.

Consequently, heat-treatment in sequencing batch reactor process would be a useful and simple technology for reducing excess sludge production in wastewater treatment process thus reducing excess sludge treatment and disposal challenges for wastewater treatment plants from economical and environmental viewpoint.

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