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Investigation of Minimization of Excess Sludge Production in Sequencing Batch Reactor by Heating Some Sludge

MARYAM PAZOKI†, AFSHIN TAKDASTAN* and NEMATOLLAH JAAFARZADEH
Department of Environmental Health,
Ahvaz Jondi Shapour University of Medical Sciences, Ahvaz, Iran
E-mail: afshin_ir@yahoo.com

The ultimate disposal of excess sludge generated from activated sludge processes is one of the most challenging problems for wastewater treatment. Most biological wastewater treatment processes are temperature sensitive and thus increasing process temperature is effective for reducing sludge production. In this research, Two sequencing batch reactor (SBR) reactors with of 20 L being controlled by on-line system are used. Long term (8 months) continuous experiments were conducted to identify the effect of controlled temperature up-shifting within 30 to 70 ºC for 1 h in part of sludge to reduction of biological excess sludge. After providing the steady state in the reactors, sampling and testing parameters such as COD, MLSS, MLVSS, DO, SOUR, SVI and Y coefficient were done. Overall, temperature shift to 60 ºC for 1 h shows during the solid retention time of 10 days, the kinetic yield coefficient decreases from 0.63 to 0.33. In other words reduces excess sludge up to 47 %. However the soluble COD increased slightly in the effluent and the removal percentage decreased from 89 in the control reactor to 57 in the test reactor; while the amount of SVI and SOUR in this temperature reduced to 45 mL/g and 9 mg O_2/h.gVSS, respectively. In temperature of 70 ºC no sludge was seen but effluent SCOD and turbidity was increased. It also did not meet the wastewater disposal standard and the wastewater had a bad adore.

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

INTRODUCTION

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, effluent and idle[1].

Excess sludge treatment and disposal currently represents a rising challenge for wastewater treatment plants (WWTPs) due to economic, environmental and regulation factors[2].

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†Department of Environmental Engineering, Tehran University, Tehran, Iran.

Sludge production is one the major features in the biological treatment of wastewater. 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].

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[4]. Second way 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[5]. Third way is to innovatively manage existing outlets of sludge disposal[6], 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[7], membrane methods[2]. However, the biological response of the sludge matrix induced by heat-treatment was poorly understood[8].

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 the increase of sludge production, *i.e.* the sludge production at 8 ºC in the activated sludge process was increased by *ca.* 12-20 % compared[9] with that at 20 ºC.

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 was achieved when the returned sludge passed through a thermal treatment loop (90 ºC for 3 h)[2].

The reduction of excess sludge by heat-treatment is induced by sludge lysis and further cryptic growth (lysis-cryptic growth)[7]. 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[10].

High temperatures can also be combined with acid or alkaline treatment to reduce or condition 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[11,12]. Their results showed that alkaline treatment by NaOH addition combined with thermal treatment (pH 10, 60 ºC 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 work, part of sludge was heated in a temperature from 30 to 70 ºC for 1 h to reduce biological excess sludge.

EXPERIMENTAL

Reactor: The reactors consisted of two cylindrical sequencing batch reactor (25 cm inner diameter × 60 cm height), made of poly glass, 20 L of efficient volume and treatment capacity of 10 L in each cycle were used.

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 (SBR)

Stages	Time
Fulfilling	3 min
Aeration	240 min
Settlement	105 min
Drainage	12 min
Idle	60 min (for heating the sludge)

Stages control and synthetic wastewater characteristics: Since the control of different operation stages in accordance with time is of great importance in the system of the SBR, a computerized system along with its auxiliary parts was used to adjust and control the different stages and measure and record the data coming from the concentrations of the dissolved oxygen, temperature and pH. It should be noted that the amount of dissolved oxygen was kept as much as 1.5 to 2.0 mg/h.

Fig. 1 demonstrate the schematic diagram of sequencing batch reactors (SBR). Detailed operational conditions are present 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 (wastewater temperature)	30, 40, 50, 60, 70
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

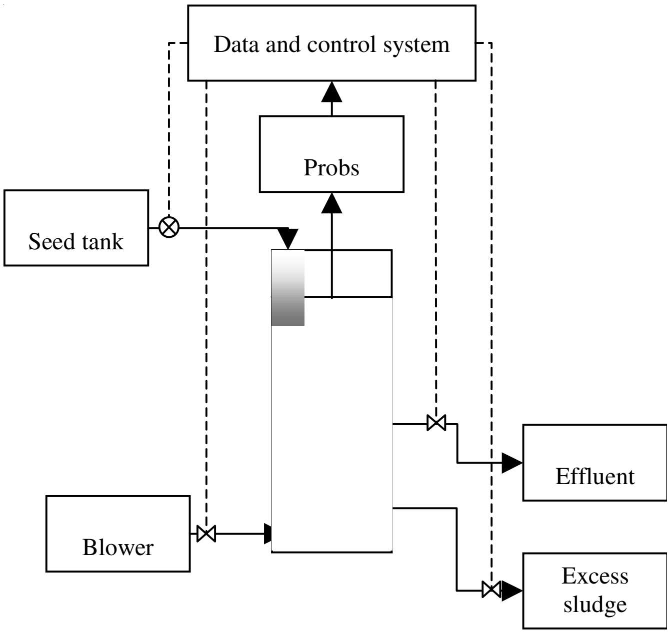

Fig. 1. General View of sequence batch reactor (SBR) schematic

Pilot start up: First, seed chosen from the returned activated sludge of Ikbatan, wastewater treatment plant (Tehran). To operate the SBR reactor, about 4 L of the aforementioned sludge were used for a SBR reactor with capacity 20 L. Next, the synthetic wastewater was added to the reactor.

Aeration and reaction of 2 weeks performed to establish of flocs, during this reaction process, synthetic wastewater was added to the reactor every day. After this stage, SBR started up with 5 cycle's *i.e.* fulfilling, reaction, wastewater drainage, sludge drainage and idle. One thermostat was installed to heat the part of sludge during idle stage. After heating the remained sludge for 1 h the reactor was filled by wastewater. The parameters of COD, SS and pH of wastewater were tested and compared with previous data. After 2 weeks of pilot run, effluent COD data were close to each other in which this phenomenon was demonstration of start up ending.

After reaching to steady state and stable situation in pilot running, the parameters of COD, BOD_5, MLSS, MLVSS, SVI, SOUR and Yielding kinetics tested during 8 months. The tests were performed according to standard methods for the examination of water and wastewater[13].

Variable situation: Due to the changes sludge temperature, at least 2 weeks were considered for the system to be adopted with the new situation. Then, the data gathered after stable situations. The suspended solid concentration in SBR and effluent wastewater COD considered as factors of the stability condition. According to standard methods for water and wastewater examination, this process was repeated three times, where the result was obtained *via* averaging them[13].

RESULTS AND DISCUSSION

Effect on sludge yield coefficient: During the 10 day cell retention time, the amount of yield coefficient was 0.63 $\frac{\text{mg Biomass}}{\text{mg COD}}$ in the wastewater temperature. Biomass co-efficiency production during Yield operation was calculated by the following relation:

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

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

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

where S, S_0 are the primary and ultimate substrate concentration (mg/L), respectively and X, X_0 are the primary and ultimate biomass concentration (mg/L)[14,15], respectively.

The biosynthetic coefficient rate of biomass (Y) with different temperature heated to part of sludge in 1 h shows in Table-3. As Table-3 shows at 50 and 60 ºC, the values of biomass production are 0.39 and 0. 33 mg biomass/mg COD, respectively.

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

Sludge temperature (ºC)	Y $\frac{\text{mg Biomass}}{\text{mg COD}}$	COD removal (%)	SVI (mL/g)	SOUR (mgO_2/h gVSS)	DS (%)	Sludge reduction (%)
23 (wastewater temperature)	0.63	90	95	21	1.1	-
30	0.69	92	120	25	0.8	Increase (9 %)
40	0.73	93	140	25	0.7	Increase (16 %)
50	0.39	79	80	14	1.3	39
60	0.33	57	45	9	2.2	47
70	-	10	0	3	0.0	100

In the wastewater temperature (23 ºC) with COD = 500 mg/L, the yield coefficient equals 0.63 mg biomass/mg COD (Fig. 2). But with temperature up-shifting to 40 ºC for 1 h in part of sludge the Yield coefficient increases to 0.73 mg biomass/mg COD because with increasing the temperature up to 40 ºC the bacterial activities become 2-3 times as much and degradable velocity of organic matter and the amount of biomass production are increased, then the amount of yield coefficient is also increased.

Raising the temperature up to 60 ºC, decreases the yield coefficient to 0.33 because sludge bacterial cell lysis and many microorganisms die in the reactor (except for limited number of slime microorganisms which can tolerate).

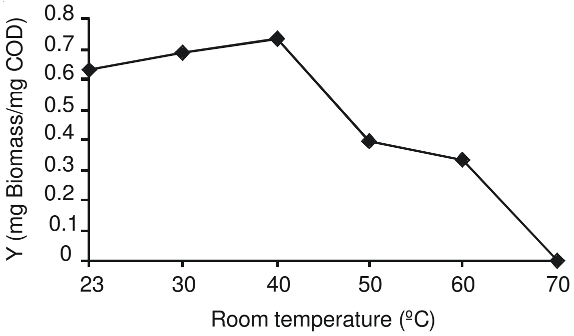

Fig. 2. Effect of temperature on Yield coefficient

Effect on COD removal: Fig. 3 shows the effect of different temperatures on the COD removal percentage. The increase of SCOD levels in the treated effluent as a result of the temperature-up-shifts are explained by the solubilization of extracellular polymeric substance (EPS), decreased sludge substrate removal capacity and microbial lysis[16]. According to Fig. 3, no impact of temperature shifts on sludge lysis has been observed when shifting sludge from 23 to 30 ºC and then to 40 ºC, but massive cell lysis occurred when shifted from 40 to 60 ºC.

With raising temperature up to 60 ºC, the COD removal percentage decreases and reaches less than 60 %. Nevertheless, heating at temperatures higher than 60 ºC causing cell inactivation and killing a lot of heterotrophic microorganisms the soluble COD rate increases appreciably in the effluent.

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

Sagastume[16] observed that increase the temperature from 30 to 45 ºC in activated sludge system, decreased the SCOD removal efficiency up to 20 %.

Effect on SVI: According to Fig. 4, as the temperature is increased from 40 to 60 ºC the SVI decreases. For example, at the temperature of 60 ºC, SVI abates to around 45 mL/g. On the other hand having increased temperature, the MLVSS/ MLSS ratio decreases, thus light increasing the specific weight of sludge.

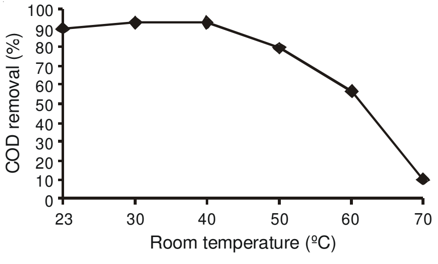

Fig. 3. Effect of temperature on COD removal percentage

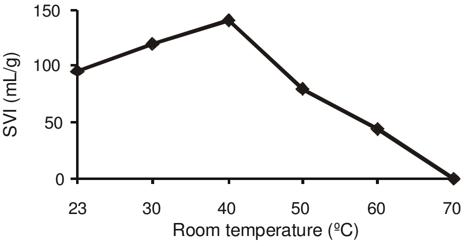

Fig. 4. Effect of temperature on SVI

Effect on specific oxygen uptake rate (SOUR): There is uncertainty in the relationship between specific oxygen uptake rate (SOURs) and temperature. Barr[17] postulated that SOURs may decrease with increasing temperature and that SOURs at high SRTs may be high due to endogenous respiration.

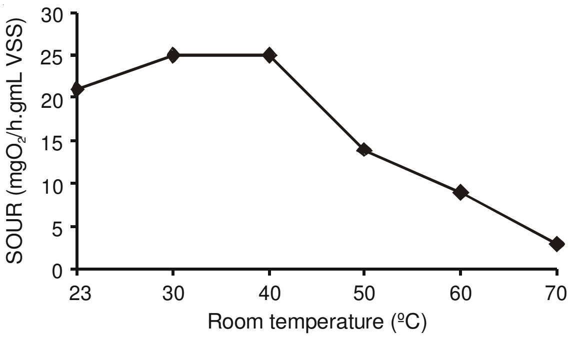

Fig. 5. Effect of temperature on SOUR

According to Fig. 5, along with the increase of temperature from 40 to 60 ºC, oxygen consumption rate reduces because of the killing of a significant portion of microorganisms therefore the SOUR rate reduces in accordance with each mg of oxygen in h/g of volatile suspended solids. As a result in the temperature of 70 ºC in part of sludge, SOUR lowered to 3 mg O_2/h.g VSS. This happens because of the temperature's sublethal metabolic inhibition (Table-4).

TABLE-4
SOUR AND OXYGEN CONSUMPTION RATE IN DIFFERENT CONDITIONS [Ref. 16]

Significance	Oxygen consumption rate	SOUR (mg/h gVSS)
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

Comparison of effluent COD with wastewater disposal and reuse standard: Fig. 6 shows the comparison of effluent wastewater COD with Iran wastewater disposal standard and agricultural reuse standard in different temperatures. As Fig. 7 shows, in 10 day solid retention time in a temperature higher than 40 ºC the amount of effluent COD can not reach to wastewater standard disposal. However from 40-60 ºC it meets the agricultural reuse standard. In temperature higher than 60 ºC, no standard is met.

Table-5 shows the comparison of results of this study with other thermal techniques for reduction of sludge production.

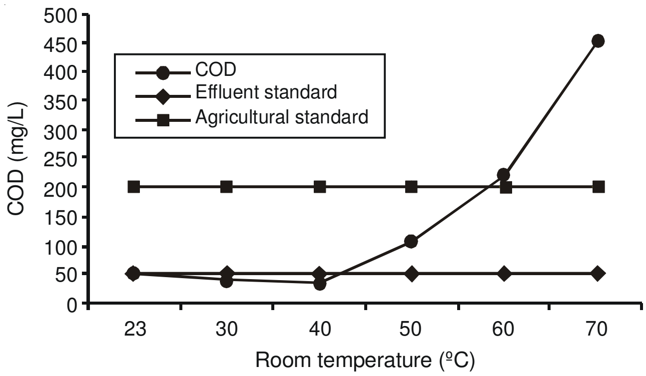

Fig. 6. Comparison of effluent wastewater COD removal with Iran wastewater disposal standard and agricultural reuse standard in different temperatures

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

Operation condition	Sludge reduction (%)	Ref.
Urban wastewater, 65 ºC, 48 h	80	18
Thermal or thermo-chemical treatment lab scale (90 ºC, 3 h), membrane bioreactor, synthetic wastewater	60	2
Lab scale (60 ºC for 20 min, pH = 10), synthetic wastewater	37	12
Pilot plant scale, synthetic wastewater, temperature up-shifting in part of sludge, (50 to 70 ºC, 1 h), sequence batch reactor		This study
1. Temperature up-shifting to 50 ºC	39	
2. Temperature up-shifting to 60 ºC	47	
3. Temperature up-shifting to 70 ºC	100	

Conclusion

Heat-treatment is considered to be simple to operate compared with other treatments such as ozonation, chlorination, *etc.*

The experiment demonstrates that: (a) With shifting temperature up to 60 ºC, the COD removal percentage decreases and reaches less than 60 % due to solubilization of extra-cellular polymeric substance (EPS) and microbial lysis. (b) The amount of SOUR and SVI in this temperature (60 ºC) are reduced to 9 mgO_2/h.gVSS and 45 mL/g respectively. (c) In the wastewater temperature, the yield coefficient equals 0.63 mg biomass/mgCOD. But with temperature to 40 ºC for 1 h in part of sludge the yield coefficient increases from 0.63 to 0.73. (d) Increasing the temperature up to 60 ºC, decreases the yield coefficient to 0.33 due to sludge bacterial cell lysis and dieing many microorganisms in the reactor. In other words, reduces excess sludge up to 47 %. (e) In the high temperature, (70 ºC) no biological excess sludge is produced, but the effluent COD is increase and no wastewater reuse standard is met.

Consequently, heat-treatment combined SBR process would be a useful and simple technology for reducing excess sludge production. So that this method can be further technically and economically assessed.

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