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Aeration Ratio Effect on Efficiency of Organic Materials Removal in Sequencing Batch Reactors

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Abstract: In this study, the effects of aeration ratio on organic materials removal rate in sequencing batch reactors was considered. Eight hours cycles, including 6 h aeration period, were applied. Raw wastewater with COD equal 350±20 mg L^{-1} was prepared by dried confectionary milk and tap water. SOTE equation in test condition was defined as $y=1.24981\ln(x)+13.86231$. Aeration ratio was described as ratio of supplied dissolved oxygen to required oxygen amount. Taking into account nitrification and denitrification processes, five aeration ratios: 1.1, 3.14, 5.44, 6.97 and 8.83 are applied. Results showed aeration ratios, above stoichiometric required oxygen amount, do not have a significant effect on organic materials removal efficiency and just slope of curve of COD changes via time, changed moderately.

Key words: Sequencing batch reactor, aeration ratio, standard oxygen transfer efficiency, organic material, dissolved oxygen

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INTRODUCTION

Aeration rate effects on required air volume and investment and operation costs of wastewater treatment plant as a result. Generally, aeration energy incorporates 50-90% of total energy consumption and more than 30% of operation cost. Optimization of aeration rate can saves 25-40% and in some cases 50% of energy cost[1].

One operation cycle of SBR contains filling, reaction, sedimentation, discharge and idle steps. Wastewater charges to system in filling step[2]. At the beginning of reaction step, concentration of organic materials especially its soluble biodegradable part, accordingly food to microorganisms' ratio, is high. As a result, microorganisms activity is not limited by substrate and their activity rate arise. Therefore, oxygen consumption rate will increase severely. Because of high oxygen concentration gradient, it expects the aeration efficiency increase.

Therefore, it is expected that oxygen utilization rate and oxygen transfer efficiency and as a result, required aeration rates in SBR systems, is different with continuous complete mix systems.

Base on Monod half saturation equation, rate of organic material removal in biological systems presents as the follow:

$$\mu = \mu_{max} \frac{S}{K_s+S}$$

That S is substrate concentration, K_s is half saturation constant, μ_{max} is maximum consumption rate and μ is consumption rate.

In complete mix continuous systems, K_s, μ_{max} and substrate concentration are constant. Therefore, nutrients consumption rate has a constant value. However, in batch systems such as sequencing batch reactors, these values change during the reaction time. Therefore, it expects that the rate of nutrient consumption change by time.

Organic material removal kinetics could be divided to three separate sections in sequencing batch reactors.

First section is started with the reaction phase. Normally, at this section, F/M ratio is high and soluble biodegradable part of substrate, is consumed. It expects there is no limitation in organic materials consumption. In this case $S>>K_s$ and thus $\mu=\mu_{max}$. On the other word, it means consumption rate is independent from substrate concentration. Present or absent of substrate limitation depends to F/M ratio and substrate characteristics. In this section, low aeration rate can results a dissolved oxygen limitation.

After consumption of soluble biodegradable part of substrate, consumption of insoluble biodegradable part of organic materials is dominant reaction. In this case, consumption rate decrease and Monod equation could present the consumption kinetic as below:

$$\mu = \frac{dS}{dt} = \mu_{max} \frac{S}{K_s+S}$$

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In third section, external source of substrate is almost consumed and the dominate reaction is endogenous respiration. In this case, bacteria death rate restricts the consumption rate.

It should be noted that even in all sections, we could use Monod equation to present the reaction rate, but equation constants include K_s and μ_{max} as well as limiting factors in each section, are different.

Low aeration rate can have a limiting role in each section. In addition, it has a significant effect on nitrification and denitrification kinetics.

MATERIALS AND METHODS

SBR pilot: One cylindrical reactor, which was made of plexy glass, with inner diameter of 25.5 cm, 60 cm height, 20 L capacity and 10 L wastewater treatment capacity in each cycle, was used. One fine bubble membrane diffuser type ECOFLEX 250CV made by USA Diffuser Tech Co. with external diameter 255 mm is used for reactor aeration. One piston air compressor, with capacity of 250 L, supplied system air requirement.

An air regulator equipped with water and oil filters, used to adjust air pressure on one bar. An adjustable air valve controlled airflow rate.

A two bladed mixer with length of shaft equal 60 cm, that 30 cm was immersed in water, with 50-70 rpm speed were used to prepare a homogenized mixture of air and liquid, especially in low airflow rates.

Feed, treated wastewater and excess sludge were stored in three polyethylene tanks with capacity of 200, 60 and 20 L, respectively.

Due to importance of timely stages control in SBR system, as well as setting various stages and measuring and recording of dissolve oxygen and temperature, we used a computerized system with essential accessories, includes control and relays boards, dissolved oxygen and temperature probes, electrical valves, feed pump and dimmer to control mixer speed. Figure 1 present system schematic.

One operational cycle includes 3 min for filling, 6 h for reaction with aeration, 1 h and 45 min for sedimentation and 12 min for discharging. Mean cell residence time is set to 30 days.

Raw wastewater composition: Dried confectionary milk and tap water were used to prepare raw wastewater. Table 1 presents raw wastewater characteristics.

Reactors startup: To startup the reactor, we used the returned activated sludge of Gaitarieh Wastewater Treatment Plant, which is located in north of Tehran.

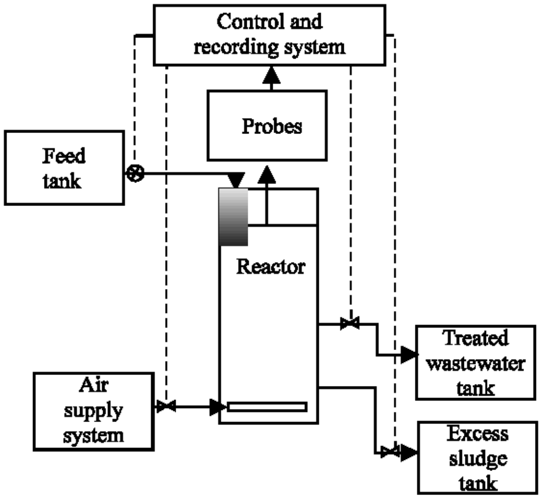

Fig. 1: Sequencing batch reactors system schematic

After each time of aeration rate’s changes, we gave minimum one week to system to adapt with new condition. Analyses were done, when the system reached steady state condition. MLSS at the end of operation cycle in the reactor is assumed as the steady state index.

Sampling: Samples were taken from feed, treated wastewater and inside of the reactor in intervals of 5, 15, 30, 60, 120, 240 and 360 min after the beginning of reaction. Samples were stored in polyethylene cap bottles with capacity of about 100 mL.

Temperature and dissolved oxygen is measured online. Air volumetric flow rate in aeration period was measured by a volumetric contour in a defined time. Samples analyses were done with sampling simultaneously to minimize samples changes.

Analysis: A sensor with 0.1 Celsius precision, measured temperature inside the reactor online. Chemical oxygen demand was analyzed through 5220-COD D closed reflux method using 16 mm vials and HACH COD reactor and DR2000 spectrophotometer, dissolved oxygen was analyzed through 4500-O G method using membrane electrode and sulfate analyzed through 4500-E SO_4 method of Standard Methods for Water and Wastewater Examinations[3].

Volumetric airflow rate was measured with a volumetric contour model Mec-Comap G1.6 Euro 2000 manufactured by Fab De Aparel Hagen Industrial L.T.D. with minimum capacity of 16 l/h and maximum capacity of 2500 l/h.

Aeration efficiency: The diffuser manufacture provides efficiency data for various conditions in depths of

Table 1: Raw wastewater composition (mg L^{-1} except pH)

Parameter	pH	COD	BOD_5	NO_3-N	NH_4-N	TKN	Org-N	P
Mean	7.55	350	211	2.6	0.4	19.4	19.0	12.4
Standard Deviation	0.23	20	12	1.5	0.2	1.2	1.3	1.6
Number of Samples	19.00	19	19	19.0	19.0	19.0	19.0	19.0

2 to 6 m (www.diffusertech.com). As the wastewater's depth in the reactor was 0.4 m, which was less than the reported data and on the other side, it was expected that aeration rate has effect on oxygen transfer efficiency, we arranged a series tests with clean tap water to measure standard oxygen transfer efficiency.

The test principle is measurement of the amount of consumed dissolved oxygen by a defined amount of sodium sulfite in a defined period of aeration with a specified aeration rate.

Sodium sulfite reacts with dissolved oxygen and converts to sodium sulfate as the following stoichiometric relation. Dissolved oxygen amount can be calculated by sulfate ion concentration measurement[4].

$$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$$

Because of relation consumed dissolved oxygen is equal:

$$1 \text{ mg DO} = 6 \text{ mg } SO_4^{2-}$$

Taking into account the reactor volume, initial dissolved oxygen and sulfate concentrations, amount and concentration of sodium sulfite added solution, final sulfate ion concentration and amount of air supplied, standard oxygen transfer efficiency is:

$$ADO_t = \{[(SO^4_t - SO^4_i) \times 1/6] - DO_i\} \times V$$

$$IDO_t = Q_{air} \times t \times 0.21 \times \rho_{air}^T$$

$$SOTE_T = \frac{ADO_t}{IDO_t}$$

Which:

DO_i = initial dissolved oxygen in reactor before aeration (mg L^{-1})
ADO_t = mass of react dissolved oxygen in reactor at time of t (mg L^{-1})
ρ_{air}^T = specific gravity of air in temperature of T, mg L^{-1}
T = inlet air temperature (°C)
SO^4_i = initial sulfate ion concentration in reactor (mg L^{-1})
SO^4_t = sulfate ion concentration at time of t (mg L^{-1})
$SOTE_t$ = Standard oxygen transfer efficiency at time (t)
IDO_t = Mass of inlet oxygen to system at time of t (mg)
Q_{air} = Air flow rate (l/min)
t = time (min)
V = reactor volume

RESULTS

Standard Oxygen Transfer Efficiency (SOTE): Aeration efficiency was measured base on SOTE by the above mentioned method. Tests were done in five aeration rates equal 43.56, 66.24, 163.8, 293.04 and 713.88 l/h. Air temperature was 23.5±1°C and water temperature was 23±0.5°C. Water volume in reactor was set 20 L. Air specific gravity in 23°C is 1423 mg L^{-1}.

Initial oxygen concentration in reactor was calculated based on average data recorded during one min before start test. Figure 2 shows percent SOTE and its changes for various aeration rates.

Correction of oxygen transfer rate: In actual operation conditions, oxygen transfer efficiency depends on temperature, saturation concentration of dissolved oxygen, mixing intensity and wastewater characteristics[5]. While the tests were done all, operation conditions except wastewater were similar. According to references values, correction factor of oxygen transfer efficiency assumed equal 0.9±0.1[1,4].

Treated wastewater quality: Table 2 presents treated wastewater quality at the end of aeration step for various aeration rates.

Table 4 presents average oxygen requirement related to COD removal efficiency, nitrification and denitrification as well as amount of oxygen supplied. Oxygen requirement is equal:

Oxygen requirement= mg input COD- mg output COD) + 4.57 mg per nitrified nitrogen – 2.86 mg denitrified nitrate

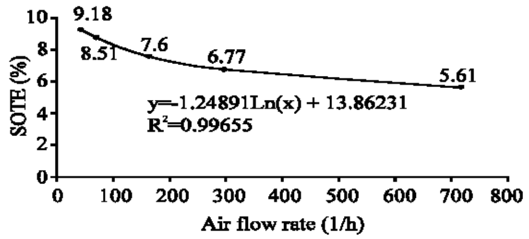

Fig. 2: SOTE vs. Aeration Rates

Table 2: Treated wastewater quality at the end of reaction step for various aeration rates

Aeration rate (l/h)	Treated wastewater quality (mg L^{-1}) COD	BOD$_5$	NO$_3$-N	NH$_4$-N	Total N
1.8±25.2	10.4	5.6	4.6	8.8	13.6
12.6±90	10.9	5.8	6.6	2.3	9.8
9±174.6	10.2	5.5	6.7	2.0	9.5
14.4±237.6	8.5	4.6	7.0	1.4	8.7
9±320.4	9.8	5.3	7.4	0.3	8.5

Table 3: Average air supply and requirement

Aeration rate (l/h)	Average oxygen requirement (mg) Nitrification and denitrification	Nitrification	Supplied oxygen (mg)	Supplied/required oxygen Nitrification and denitrification	Nitrification
25.2±1.8	3652	3891	4014	1.1	1.0
90±12.6	3836	4184	12060	3.1	2.9
174.6±9	3848	4204	20937	5.4	5.0
237.6±14.4	3869	4248	26977	7.0	6.4
320.4±9	3901	4285	34436	8.8	8.0

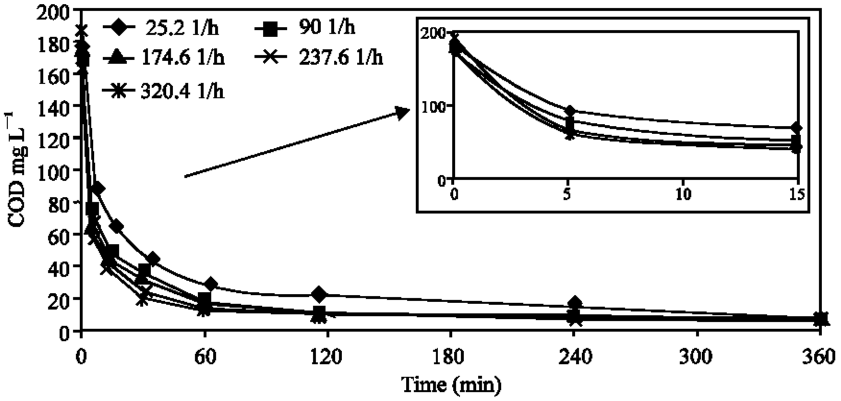

Fig. 3: COD changes vs. time in various aeration rate

Chemical oxygen demand changes with time: Figure 3 shows COD changes in reaction period inside the reactor for various aeration rates.

DISCUSSION

The results show that increase of aeration ratios more than stoichiometric values do not have a significant effect on organic material efficiency. Taking into account the raw wastewater characteristics, most of organic materials especially soluble biodegradable part of it, is removed at the beginning of reaction stage.

Low aeration ratios result, dissolved oxygen acts as a limiting factor at the beginning of reaction stage. Therefore, COD reduction curve slope decreased. Figure 4 presents this approach. In addition, nitrification and denitrification are two other subjects, which should be considered. In fact, it is not possible to prevent nitrification even in low aeration ratios. Hence, oxygen requirement should be calculated base on both of organic materials removal and nitrification.

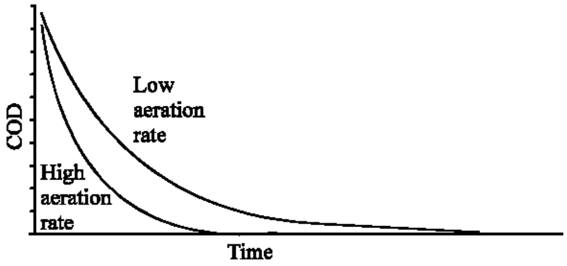

Fig. 4: Aeration rate effect on COD reduction dynamic

Aeration rate has a complicated effect on nitrification and denitrification processes. Some of the most important effective parameters on these processes are initial concentration of nitrogen compounds inside the reactor, aeration rate, biological floc size, amount and characteristics of available organic materials. Authors will describe these issues in another study.

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