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Treatment of decentralized molasses wastewater using anaerobic baffled reactor

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ABSTRACT

The anaerobic baffled reactor (ABR) was used to remove carbonaceous organic pollutants from decentralized molasses wastewater in the study. The anaerobic chambers were inoculated with anaerobic granule sludge. The ABR was studied regarding the hydraulic retention time, the pH, and gas production velocity. After the ABR was seeded with sludge, the organic loading rate was increased gradually from 1.5 to 3.6 kg/m^3 d. The average chemical oxygen demand (COD) removal efficiency was about 90% and it was attributed to the high resistance of COD and hydraulic shock loads. The COD removal efficiency and the gas production velocity of the first chamber were the highest compared with other chambers. In addition, the volatile suspended solids to total suspended solids ratio of the first chamber was maximum.

Keywords: Anaerobic baffled reactor; Molasses wastewater; Organic loading rate; COD removal

1. Introduction

With the food industry development, significant amounts of wastewater has been produced. Especially, the molasses wastewater has the characteristics of high biodegradability, variable water quality, and water flow. In western China, there is a lack of water resources. The molasses wastewater is one of the main water pollution sources due to the high concentration of organic pollutants [1]. However, most sugar processing factories are distributed dispersedly in the country. Thus, it is not convenient to treat all the molasses wastewater together. It is necessary to design the mobile equipment for treating decentralized molasses wastewater in western China.

Anaerobic biological treatment of high concentration food wastewater has become an established pollution control technology. There are some anaerobic reactors for the wastewater treatment. The upflow anaerobic sludge bed (UASB) and expanded granular sludge bed have been developed. The anaerobic baffled reactor (ABR) has many advantages over other anaerobic reactors. The advantages include the simple design with no special gas or sludge separation equipment, lower hydraulic retention time (HRT), and higher resistance to chemical oxygen demand (COD) and hydraulic shock loads [1–5].

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Among high efficient anaerobic reactors, ABR is considered to be a promising reactor for industrial wastewater treatment [2]. The ABR was applied to treat printing and dyeing wastewater [3], whisky distillery wastewater [4], nitrobenzene wastewater [5], soybean protein processing wastewater [6], and landfill leachate [7]. However, the limited studies were carried out to treat the decentralized molasses wastewater by an ABR. It is necessary to evaluate the feasibility of an ABR on the decentralized molasses wastewater treatment.

The study investigated the performance of an ABR for the decentralized molasses wastewater treatment. The purpose of the study was to assess and optimize the COD removal from molasses wastewater with the ABR under various operational conditions. The high-efficiency and economical reactor was optimized for COD removal from decentralized molasses wastewater.

2. Materials and methods

2.1. Experimental setup

Fig. 1 shows the schematic diagram of the ABR used in the study. The ABR has a working volume of 21.6 L and is consisted of four discrete chambers of equal volume. The anaerobic chambers were inoculated with anaerobic granule sludge taken from Brewing Wastewater Treatment Plant of Shanghai, China. The volatile suspended solid (VSS) to the suspended solid (SS) ratio of anaerobic granule sludge was 0.60. Each chamber was divided into down-comer and up-comer regions by slanted edge (45˚) baffles to encourage mixing within each chamber. The liquid flowed alternatively upwards and downwards between chamber partitions. It is beneficial for the homogenous distribution of wastewater and it promoted the mixing between organic substances and the biomass in the bottom of each up-comer [10]. The width of the down-comer and the up-comer were 2 and 6 cm, respectively. The liquid sampling ports were located in the middle of each compartment. The sludge sampling ports were located in the bottom of each compartment. The influent was pumped using a peristaltic pump.

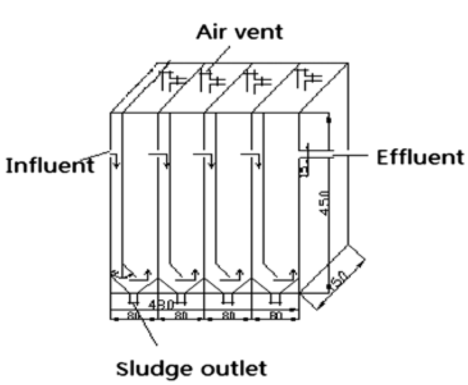

Fig. 1. Schematic diagram of the ABR.

2.2. Simulated molasses wastewater

Based on the past surveys and literatures [8–10] regarding decentralized molasses wastewater in China, the characteristics of the wastewater are shown in Table 1.

The influent was simulated in the laboratory. Glucose was used as the main source of COD because most of the decentralized molasses wastewater is from cane-based sugar mills. Ammonia and phosphorous were stimulated with NH_4Cl and KH_2PO_4, respectively. $NaHCO_3$ was used to stimulate the pH of the influent. The pH of the influent was about 7–8. In addition, trace elements were also added to the influent for promoting biomass growth.

2.3. Analytical methods

The COD concentration was measured by the standard method [11]. The pH value was measured by the pH-meter (PHS-25; Shanghai REX Instrument factory, China). The SS and VSS values were measured by the gravimetric method. The gas was collected to analyze the gas production velocity. After 60 d of cultivation, the sludge was extracted from the anaerobic chambers and the microscope (CQ500-C) was used to examine the sludge morphology.

2.4. The ABR operation

As shown in Table 2, the ABR was operated at constant influent COD concentration and various HRT. The organic loading rate (OLR) was increased by reducing HRT. The OLR was increased as the steady state achieved under the existing operation condition. During this period, the COD concentration and removal efficiency, the effluent pH and the gas production velocity were studied.

3. Result and discussion

3.1. The COD removal

During the operation of the ABR, the HRT was various as the influent COD concentration was

Table 1
Recipe for simulated wastewater

Parameters	pH	Temperature (℃)	COD (mg/L)	BOD (mg/L)	TP (mg/L)	TN (mg/L)
Numerical value	6.7–7.5	35	600-3,000	500-2,800	6–23	50–85

Table 2
The operational parameters of the ABR

Operation stage	HRT/h	Influent COD/(mg/L)	OLR (kg COD/m^3 d)
1st stage (1–31 d)	48	3,000	1.5
2nd stage (32–43 d)	36	3,000	2
3rd stage (44–53 d)	24	3,000	3
4th stage (54–57 d)	20	3,000	3.6

constant. In the beginning, the OLR of the influent was low and about 1.5 kg COD/m^3 d. It was beneficial for the bacteria growth in each chamber. The acclimation of bacteria in each chamber is very vital for the quick startup of the ABR.

From Figs. 2 and 3, the COD concentration of each chamber decreased dramatically during the first 30 d. The effluent COD was about 250 mg/L and COD removal efficiency of the ABR reached about 90%. It also indicated that the bacteria adapted to the environment of each chamber and the bacteria activities were recovered. As the HRT decreased from 48 to 36 h, the influent OLR was increased from 1.5 to 2 kg/m^3 d and the COD removal efficiency was also decreased. It was because the influent organics did not mix with the bacteria of each chamber completely for the biodegradation of organic substances. However, the COD removal efficiency of each chamber was stable again after 10 d. Then the OLR increased from 2 to 3.6 kg/m^3 d, the COD concentration and removal

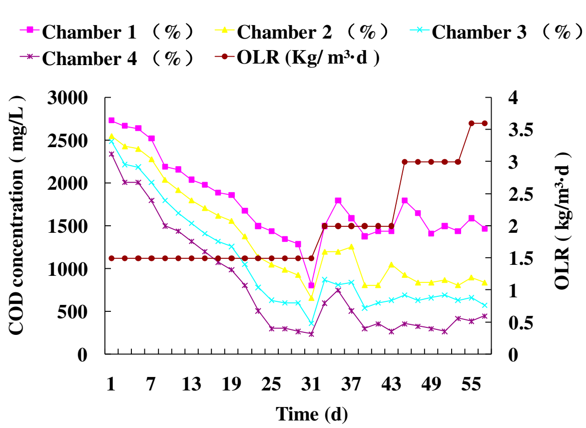

Fig. 2. Time variation of the effluent COD concentration of each chamber at various OLR.

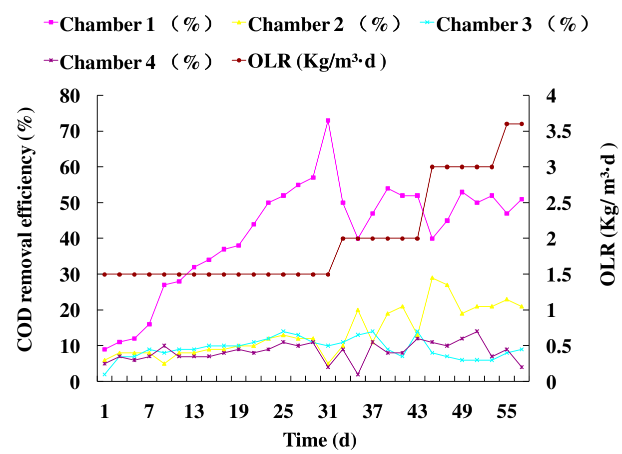

Fig. 3. Time variation of the COD removal efficiencies of each chamber at various OLR.

efficiency of each chamber were changed slightly. The performance of the ABR was not influenced greatly. It verified that the ABR was able to resist OLR shock for being operated stably.

3.2. Characteristics of pH variation

The pH value is an important parameter for anaerobic bacteria growth. The optimum pH for methanogenic bacteria growth in anaerobic reactor is between 6.8 and 7.2. If the pH is less than 5.0 or more than 8.5, the methanogenic bacteria growth will be inhibited [12]. Fig. 4 shows the variation of pH in each chamber and the pH value of the influent was between 7.0 and 8.0. From Fig. 4, the average pH of every chamber was about 6.5 at first. Then the pH was increased to about 7.0 because the methane generation process from acetic acid was very slow. As the methanogenic bacteria were activated, the pH was increased and

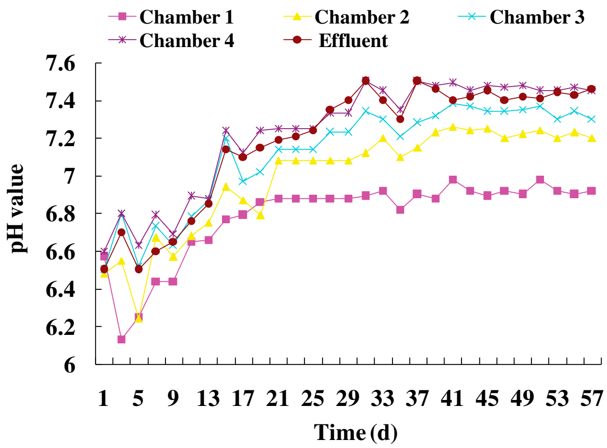

Fig. 4. The variation of pH in each chamber.

remained at 7.0. It was beneficial for methanogenic bacteria growth and enhancing COD removal efficiency of the ABR.

3.3. Gas production

As shown in Fig. 5, the gas production of the first chamber was maximum because the OLR was low at first and no organic acids were accumulated. The over acidification did not happen. The organic acids generated in the first chamber were quickly degraded by the methanogenic bacteria. Thus, the methane gas production of the first chamber was maximum compared with the other chambers. As the OLR was increased, the gas production velocities of the first two chambers were increased because most of the organic pollutants were biodegraded in the first two chambers.

3.4. The performance of the ABR at various HRT

The HRT is positively related with COD removal efficiency [13]. As the HRT increased, the contact time

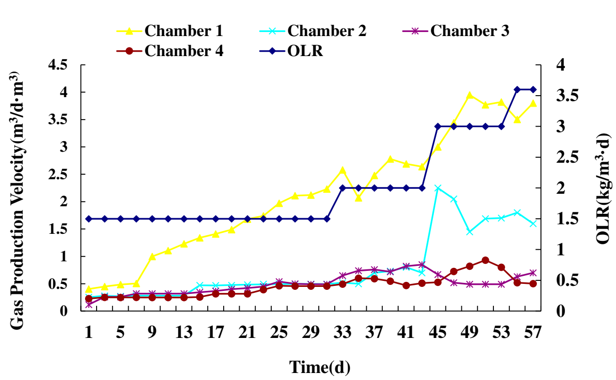

Fig. 5. The correlation between the gas production velocity and OLR.

of micro-organisms and substances was increased. It was beneficial for micro-organisms to degrade the organic substances completely. From Table 3, as the influent COD concentration was constant and the HRT decreased from 48 to 36 h, the COD removal efficiency of the first chamber was decreased by 20% due to the channeling [14]. However, the COD removal efficiencies of the second and third chambers were increased as the HRT decreased because the chambers of the ABR were separate and the other chambers but the first chamber were affected by the OLR shock. As the HRT was 48 h, the COD removal efficiencies of the first two chambers were higher than those of the latter two chambers. It was because the substances degraded by micro-organisms were increased as the HRT decreased and influent COD remained constant.

The COD removal efficiency of the ABR was not dramatically decreased or increased as the HRT increased. Therefore, as the HRT increased, the COD removal efficiency of the ABR was not enhanced significantly. The HRT is one of the important parameters to affect the COD removal efficiency of the ABR and the optimum HRT should be determined based on the operation condition. In this study, the optimum HRT was 24 h according to the COD removal efficiency and the investment.

3.5. Microphotographs of the sludge

The Fig. 6(A)–(D) shows the morphology of the sludge in the first, second, third and fourth chambers, respectively. Since the influent quality of each chamber in the ABR was different, the granule sludge in each chamber was not the same. Each chamber of the ABR was like UASB. The size of the sludge in the first chamber was maximum (about 3–5 mm) and the large granule sludge was consisted of many small particles. Since most of influent COD was removed in the first chamber, the size of the granule sludge in the first chamber was maximum. In the second chamber, the size of granule sludge was smaller than that of the sludge in the first chamber and the granule sludge was gray and compact. The sludge particle of the third chamber was small and black with the smooth surface. The sludge size of the fourth chamber was smaller than that of the third chamber and the color of the sludge was dark.

3.6. The VSS/SS ratio of anaerobic granule sludge

Fig. 7 shows the VSS/SS ratios of anaerobic granule sludge in each chamber at various OLR. The VSS/SS ratio of granule sludge in each chamber was

Table 3
The COD concentration and removal efficiency of each chamber at various HRT.

	The COD concentration (mg/L)					The COD removal efficiency (%)				
HRT (h)	Influent	1	2	3	4	1	2	3	4	Effluent
48	3,000	800	510	330	240	73	10	6	3	92
36	3,000	1,410	810	450	295	53	20	12	5	90
24	3,000	1,450	780	480	270	52	22	10	7	91
20	3,000	1,480	840	570	360	51	21	9	7	88

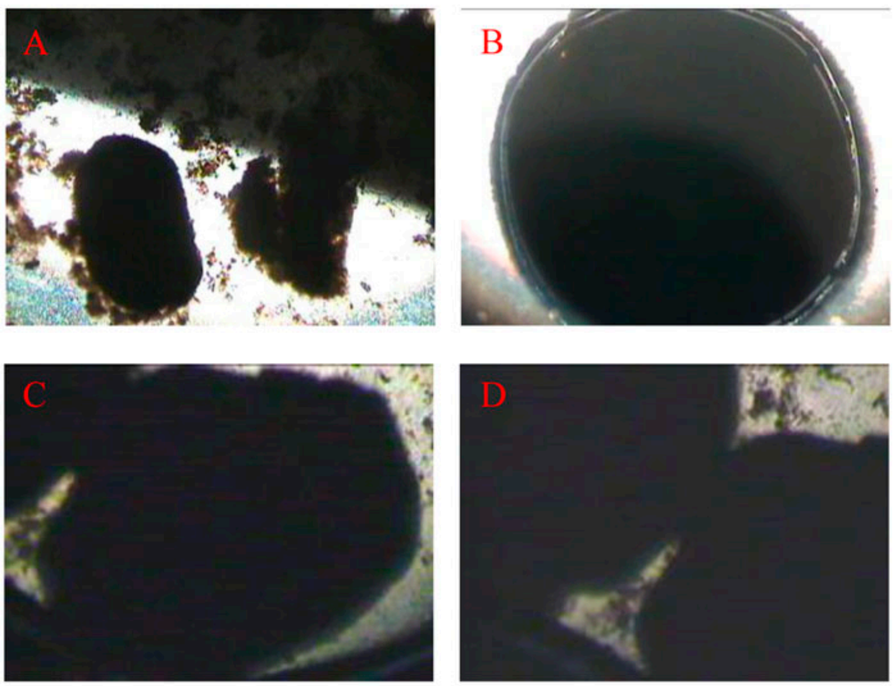

Fig. 6. The microphotographs of the granule sludge in the first (A), the second (B), the third (C), and the fourth (D) chamber of the ABR.

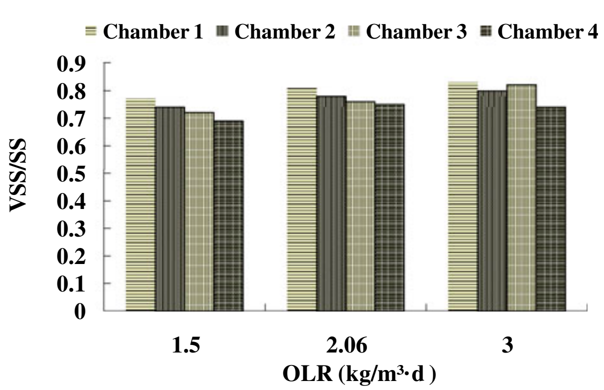

Fig. 7. Variation of VSS/SS in each chamber at the OLR of 1.5, 2.06, and 3 kg/m^3 d.

increased as the OLR increased. It indicated that the amount of micro-organisms was increased as the OLR increased due to the good acclimation of micro-organisms. The VSS/SS ratio of the sludge in the first chamber was maximum. It was consistent with the biogas production rate because the OLR of the first chamber was maximum and the highest COD concentration in the first chamber promoted the micro-organisms growth.

4. Conclusions

The ABR is a promising reactor for the molasses wastewater treatment. Based on the experimental results, the conclusions are as follows:

(1) High removal efficiency of COD was achieved in the ABR for treating molasses wastewater with the COD of 600–3000 mg/L at the HRT of 24 h.
(2) The ABR has the high ability of resisting the OLR shock due to the compartmentalized system.
(3) In the first chamber, the gas production was highest and the VSS/SS of the sludge was maximum.

Acknowledgments

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