Journal of Beijing Institute of Technology, 2007, Vol. 16, No. 4

Effect of Dissolved Oxygen on Operation of EGSB

LI Hui-li (李慧莉), LÜ Bing-nan (吕炳南), LI Qing-wei (李清伟)
(School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin 150090, China)

Abstract: An expanded granular sludge bed (EGSB) reactor was adopted to study the dissolved oxygen (DO) effect on the operation. With the chemical oxygen demand (COD) 800 - 1 800 mg/L, pH 6.0 - 7.3, volume loading rate (VLR) 5.4 - 11.5 kg COD/(m^3·d), the operational behaviors of EGSB reactor was researched. And the max DO concentration which influenced steady operation of EGSB reactor was determined by contrasting the changes due to different concentrations of the influent DO. With the COD 1 200 - 2 000 mg/L, VLR 7.2 - 12.0 kg COD/(m^3·d), the operational characteristic of EGSB reactor was researched by aerating the recycle effluent. The results was: when the DO concentration of influent was under 3.0 mg/L, the removal efficiency of COD was 82% - 90% and the operation of the EGSB reactor was steady; when the DO concentration of influent was over 3.0 mg/L, the oxidation-reduction potential (ORP) fluctuated greatly and the operation of the EGSB reactor was instable; the acidified wastewater of saccharide whose pH value was 5.1 - 6.5 could be treated by aerating the recycle effluent and the efficiency of COD was up to 85% - 92%.

Key words: expanded granular sludge reactor; oxidation-reduction potential; dissolved oxygen
CLC number: X703.1 **Document code:** A **Article ID:** 1004-0579(2007)04-0486-06

It was usually considered that dissolved oxygen (DO, mg/L) was toxic to anaerobic microorganism[1]. However, anti-shock ability of anaerobic microbe in up-flow anaerobic sludge blanket (UASB) reactor and expanded granular sludge bed (EGSB) reactor was enhanced by forming granule sludge and containing a great amount of facultative bacteria. Kato treated ethanol wastewater with two EGSB reactors, and the results showed that efficiency of treatment was similar when one reactor was anaerobic while the other was with higher dissolved oxygen (tiptop was up to 3.8 mg/L). The removal efficiency of chemical oxygen demand (COD, mg/L) was slightly increased under the microaerobic condition in contrast to anaerobic condition. Furthermore, the substance difficult to treat or toxicant could be efficiently treated when dissolved oxygen existed in the reactor[2-5].

Acidified wastewater whose pH value was below 6.0 could be treated with the EGSB reactor. When volume loading rate (VLR) was up to 5.0 kg COD/(m^3·d), the average removal efficiency of COD was over 90%[6-7].

The EGSB reactor was adopted to study the DO effect on the operation of anaerobic reactor and treatment of acidified wastewater.

1 Materials and Methods

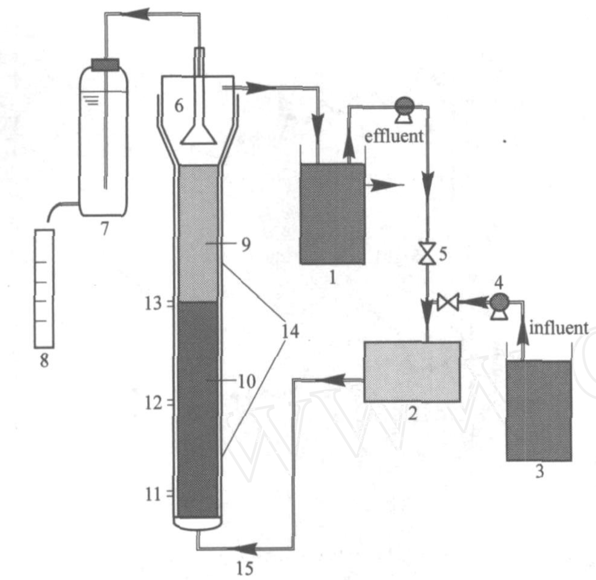
1.1 EGSB System

The EGSB reactor had a volume of 12.5 L, including a 10 L reaction zone, a height of 1.6 m and an internal diameter of reaction zone of 90 mm with the ratio of height to diameter being 17∶1. A hot water bath was used to heat influent and recycle effluent, and the insulation stuff was used to maintain reactor's temperature at 33 ℃. The scheme of EGSB reactor is shown in Fig. 1. The raw water and recycled water were fed into the reactor with a peristaltic pump. The methane gas was collected with a Mariotte bottle unit.

Received 2006-09-15
Sponsored by the National "863" Program Project (2003AA601090)
Biographies LI Hui-li (1970 -), doctoral sutdent, hemagogo@tom,com; LÜ Bing-nan (1940 -), professor, doctoral adviser.

1.2 Seeding Sludge

The inoculated granule sludge, which had been preserved for one year, came from the same wastewater. The biomass was 8.4 kg·m^{-3}, and the content ratio of volatile suspend solids (VSS, g/L) and suspend solids (SS, g/L) was 0.66. The density and maximum methanogenic activity of the seeding sludge were 1 045 kg/m^3 and 1.48 g COD_{CH_4}/gVSS·d.



1 – recycle effluent tank; 2 – water heater; 3 – influent water tank; 4 – peristaltic pump; 5 – adjust valve; 6 – three phase separator; 7 – mariotte bottle; 8 – measuring cylinder; 9 – small granule sludge; 10 – big granule sludge; 11, 12, 13 – sampling tube 1, 2, 3; 14 – material of heat preservation; 15 – EGSB reactor

Fig. 1 Scheme of experimental EGSB reactor

1.3 Characteristics of the Influent

The carbon source of influent consisted of sucrose and beer. The mol ratio of n(COD) ∶ n(N) ∶ n(P) was 100∶3∶1; the mol ratio of n(S) ∶ n(P) was 1∶2 and the mol ratio of n(S) ∶ n(Fe^{2+}) was 3∶1. Meanwhile, micronutrients were added as the following compositions: NH_4Cl, KH_2PO4, $Na_2S·9H_2O$, $FeCl_2·4H_2O$, $CoCl_2·6H_2O$, $NiCl_2·6H_2O$. The mol ratio of n(Fe^{2+}) ∶ n(Co^{2+}) ∶ n(Ni^{2+}) was 10∶1∶2. The pH value was adjusted to 6.0 - 8.0 by adding $NaHCO_3$, which could keep the suitable alkalinity. Yeast grease and $CaCO_3$ or $CaCl_2$ were added for enhancing methanogenic activity and promoting formation of granule sludge[8].

1.4 Routine Analysis

All wastewater analyses were conducted according to the standard methods[9]. COD was measured by potassium dichromate methods; SS and VSS were measured by weight methods; the sedimentation velocity of granule sludge was measured by settlement methods; the granule size distribution of granular sludge was measured by filtration methods; the methanogenic activity of granule sludge was measured by maximum methanogenic rate methods and the flow rate was measured by peristaltic pump.

1.5 Experiment Process

The experiment consisted of three stages. Detailed operation parameters were shown in Tab.1.

Tab.1 Parameters of different stages

stage/ d	DO of influent/ (mg·L^{-1})	flux of influent/ (L·h^{-1})	HRT/ h	ratio of recycle	VSS/ (mg·L^{-1})	volume loading rate/ (kg·m^{-3}·d^{-1})	concentration of COD/ (mg·L^{-1})
Ⅰ 22	3.0 - 7.4	2.0	5.0	2∶1	8.4	5.4 - 8.5	1 125 - 1 750
Ⅱ 30	< 3.0	4.0	2.5	3∶1	6.8	8.4 - 11.5	875 - 1 200
Ⅲ 38	0	2.5	4.0	5∶1	7.5	7.2 - 12.0	1 200 - 2 000

Ⅲ—aerating to the recycled effluent, the flux was 0.15 m^3/h; HRT—hydraulic retained time

2 Results and Discussion

2.1 Effect of DO between 3.0 mg/L and 7.4 mg/L

When DO of influent was over 3 mg/L, the operation of the EGSB reactor was not steady and ORP in the reactor fluctuated obviously. The highest concentration of dissolved oxygen in the reactor was up to 0.9 mg/L. The granule sludge changed the floccular shape; the settling rate declined and the COD removal efficiency went down to 72 %. Under this condition, the reproduction speed of acidification bacteria was fast leading to high concentration of VFA, and it was easy to acidify the EGSB reactor. Thereby, the quantity of added sodium bicarbonate for buffering was more than 40 % that of anaerobic operation. With the operational time prolonging, the state of the inner EGSB reactor changed from anoxic to anaerobic and ORP decreased gradually, as shown in Fig. 2.

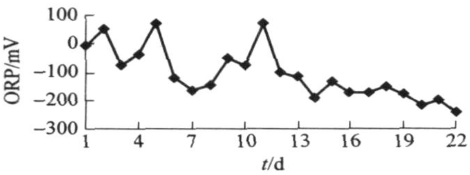


Fig. 2 ORP in the EGSB reactor

2.2 Effect of DO below 3.0 mg/L

When DO of influent was below 3.0 mg/L, the operation of the EGSB reactor was normal. The reductive substance and acidified substance (such as VFA) could be oxidized by oxygen when DO existed in wastewater. So, on the condition of the same mass of added sodium bicarbonate, the pH value of anoxic effluent was higher than that of anaerobic effluent. Under this condition, after 8 days' operation, the operation of the EGSB reactor was gradually steady and ORP in the reactor fluctuated at -180 mV. Because ORP of environment declined when microorganism grew[4], consequently, there was no negative effect on reproduction and metabolism of methanogen in the interior of the granule sludge. When trace dissolved oxygen existed in environment, the metabolized production of anaerobic bacteria could be oxidized. So, microorganism was not easily restrained by its metabolized production; methanogenic activity of bacteria was enhanced and yield of CH_4 was high and stable. After 14 days' operation, dissolved oxygen was below 0.3 mg/L; ORP fluctuated in -100 mV; the concentration of effluent VFA was low and yield of gas was stable. The results were shown in Fig. 3, Fig. 4 and Fig. 5.

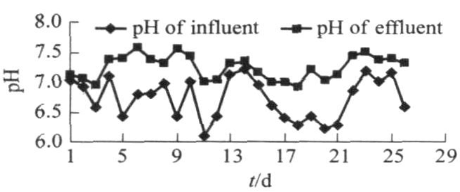


Fig. 3 pH of influent and effluent

2.3 Aerating Recycle Effluent

To aerate the recycle effluent could treat acidified wastewater. As shown in Fig. 6, the change trends of the influent and the effluent were very similar. It was found out that operation of the EGSB reactor could not be affected by the pH value of the influent, and the pH value of the effluent could be kept in a high range (7.2 - 8.2). Under this condition, the ratio of dissociative H_2S was rapidly decreased as pH value increased, and the toxicity of H_2S could be reduced.

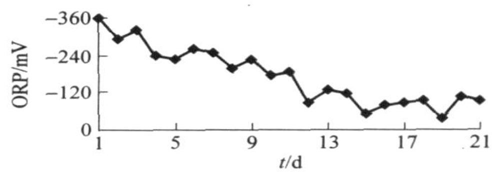


Fig. 4 ORP in the reactor

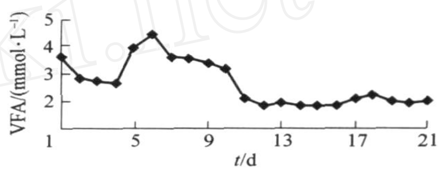


Fig. 5 VFA of effluent

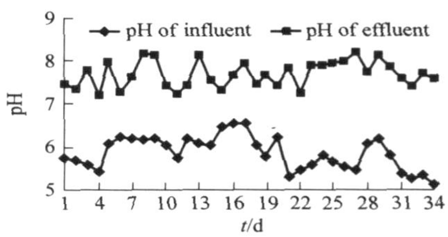


Fig. 6 pH of influent and effluent

However, it was found out that the operational state of reactor wasn't changed by measuring ORP of the recycle effluent and current in the reactor under this condition. ORP in the reactor was from -350 to -390 mV, and it was similar to that under anaerobic conditions. No dissolved oxygen was found in the reactor in that low flux of aerating and the high reductive substance of effluent led to consumption of DO of the recycle effluent. ORP of the recycle effluent changed obviously by aerating air, which was shown in Fig. 7. The change of ORP was influenced by the volatile fatty acid (VFA) of the effluent. The trend of change was similar, as shown in Fig. 8. The reason was that oxygen of the recycle effluent was used to oxide VFA of the effluent.

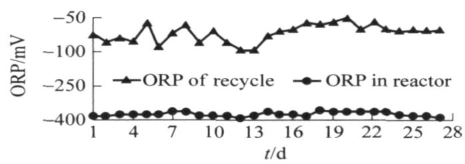


Fig. 7 ORP of the recycle water and EGSB reactor

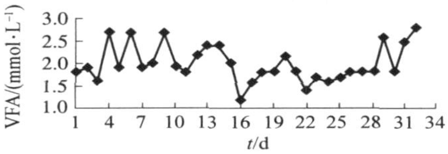


Fig. 8 VFA of the effluent

2.4 Performance of Granule Sludge

The characteristics of the granule sludge varied under different operational conditions. Therefore, the difference of the granule sludge was analyzed.

2.4.1 Configuration and Species

From Figs. 9 - 10, it was found out that the exterior of the anoxic sludge was smoother and the array of bacteria was tighter and denser than that of the anaerobic sludge by observing two batches of stereoscan photographs of the granule sludge (Fig. 9a, Fig. 10a). The density of bacteria on the surface of the anoxic sludge was greater than that of the anaerobic sludge (Fig. 9b, Fig. 10b). Most of these bacteria on the surface of the anoxic sludge were the coccus and the bacilli. The content of the extra cellular polymer (ECP) on the surface of the anaerobic sludge was higher than that of the anoxic sludge, and most of these bacteria on the surface of the anaerobic sludge were the bacilli. The content of methanosarcina in the interior of the anoxic sludge was rare; most of the bacteria were the methanococcus and methanobacterium. There were methanobacterium, methanosarcina and methanospirochaeta in the interior of the anaerobic sludge. The array of bacteria inside the anoxic sludge was close and the interstitial degree was small; the array of bacteria inside the anaerobic granule sludge was loose and the interstitial degree was high. The anoxic sludge and anaerobic sludge had different performance due to their different configurations.

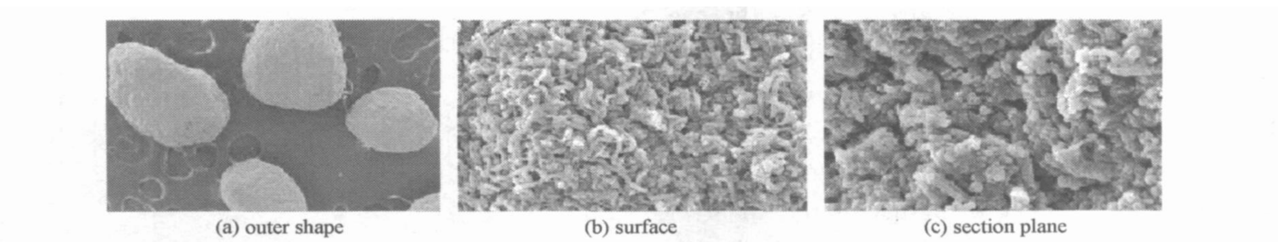


Fig. 9 Stereoscan photographs of anoxic granular sludge

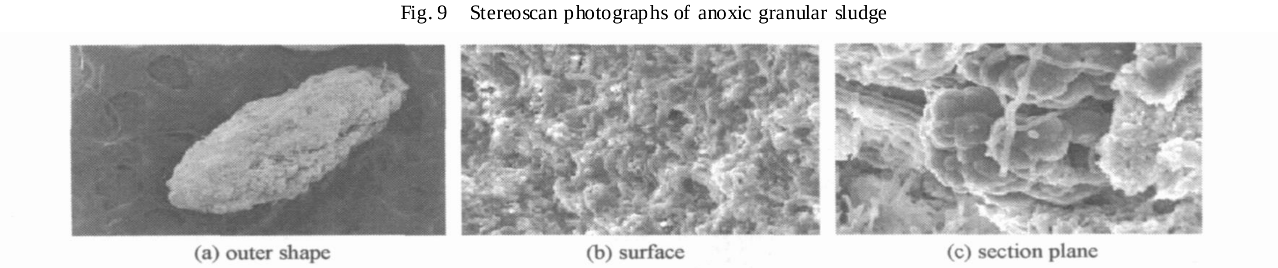


Fig. 10 Stereoscan photographs of anaerobic granular sludge

2.4.2 Methanogenic Activity of Granule Sludge

The methanogenic activity of the granule sludge was detected from sampling tube 1, tube 2 and tube 3. The results were shown in Fig. 11.

It was found out that: ① The methanogenic activityies of the anaerobic sludge from three sampling tubes were different obviously. The reproducing speed of microorganism was rapid; the concentration and methanogenic activity of the sludge in this area were higher than others because the concentration of the substance in sampling tube 1 was higher and the microorganism could obtain abundant nutriments. With the declined concentration of the substance along the longitude of the reactor, the ratio of metab-

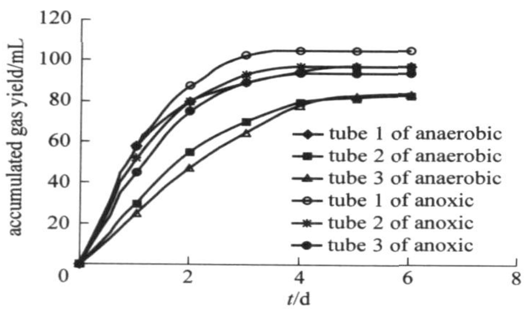


Fig. 11 Methanogenic activity of sludge

olizing substance and transferring speed of substance decreased. Both the concentration and the activity of methanogen decreased. ② The methanogenic activities of the anoxic sludge from the three sampling tubes were almost the same. The value of activity was similar or higher than that of tube 1 of the anaerobic sludge. The reason was that the content and species of microorganism on the anoxic sludge surface were higher than those of the anaerobic sludge; the ratio of metabolism and transferring substance was high; the methanogen in the interior of the anoxic sludge could obtain enough nutriments for growth. So, the concentration and activity of methanogen of the anoxic sludge was higher than those of the anaerobic sludge.

2.4.3 Settling Rate of Granule Sludge

As shown in Fig. 11, the settling rate of the anoxic sludge was higher than that of the anaerobic sludge for granules with the same size. Specially, the difference was obvious for the smaller size granules. One reason was that the configuration of the anoxic sludge was tight; the content of the microorganism was high and the density of the sludge was great. The other reason was that, on the contrary, the configuration of the anaerobic sludge was loose and the mass of the sludge was small. The high settling rate of the anoxic sludge was more helpful for keeping the higher microbial concentration, higher liquid up-flow velocity of the EGSB reactor and higher efficiency of transferring substance.

2.4.4 Size of Granule Sludge

The size of the anoxic sludge was mostly at 1.25 - 0.63 mm and the weight ratio was 58 %. This range of granule size was good for increasing contact surface area and enhancing efficiency of transferring substance. The ratio of the anoxic sludge over 1.25 mm decreased obviously and was only 28 % in contrast to 42 % of the anaerobic sludge. The surface of the anoxic sludge was tight; the content of microorganism was high; the speed of metabolism and transferring substance was high. As a result, the abundant nutrition was afforded to methanogen and the speed of producing methane was high. If the size was bigger, the methane gas produced by methanogen could not be transferred from the interior to the exterior of the granule sludge in time. Granules with bigger size containing methane floated upwards and broke up by shear force of current. So, the ratio of the bigger size declined under anoxic conditions. The ratio of the anoxic sludge below 0.63 mm decreased slightly, from 14 % to 12 %. The reason was that the settling rate of the anoxic sludge was higher than that of the anaerobic sludge for granules with the same size, which made it easy to maintain in the EGSB reactor.

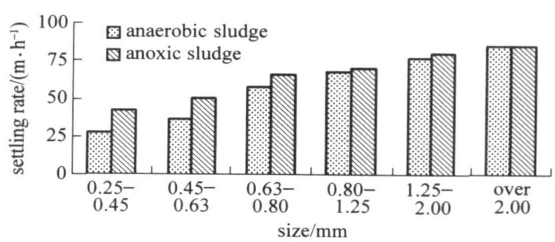


Fig. 12 Settling rate of granlue sludge

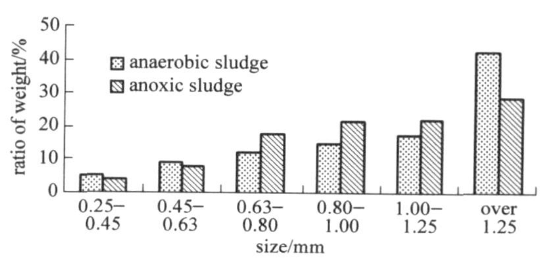


Fig. 13 Size distribution of granule sludge

3 Conclusions

By experiments, the conclusions were obtained as follows:

① When the flux of aerating recycle effluent was 0.15 m^3/h, the acidified wastewater whose pH was below 6.0 could be treated and COD removal efficiency was up to 85 % - 92 %. ORP in the reactor was lower and fluctuated from - 350 to - 390 mV, and the EGSB reactor operated under the anaerobic conditions.

② When the concentration of dissolved oxygen was below 3.0 mg/L, ORP in the reactor fluctuated in - 100 mV, and the EGSB reactor was operated under the anoxic conditions. COD removal efficiency was 82 % - 90 % and the operation of the reactor was steady.

③ The methanogenic activity and settling rate of the anoxic granule sludge were higher than those of the anaerobic granule sludge. The density and species on the surface and in the interior of the anoxic granule sludge were more than those of the anaerobic granule sludge. The main bacteria in the anoxic granule sludge were the methanococcus and methanobacterium. The size of the anoxic granule sludge was mostly between 1.25 - 0.63 mm, and it was good for enhancing efficiency of transferring substance and steady operation of the EGSB reactor.

④ When the concentration of dissolved oxygen was over 3.0 mg/L, the operation of EGSB reactor was unstable and the performance of the granule sludge deteriorated.

References:

[1] Hu Jichui. Theory and technology of anaerobic bio-treatment wastewater[M]. Beijing: China Architecturel and Building Press, 2003.

[2] Dong Chunjuan, Lü Bingnan, Ma Li, et al. Use of oxygen-limited methanogenesis technology for degradation of toxic matters in water[J]. China Water & Wastewater, 2003, 19(8):19 - 22. (in Chinese)

[3] Chen Yuanchai, Lan Huixia, Chen Zhonghao, et al. Character of anaerobic granular sludge for pentachlorophenol degradation under microaerobic condition [J]. Journal of Cellulose Science and Technology, 2005, 13(2):14 - 19. (in Chinese)

[4] Dong Chunjuan, Lü Bingnan. Performance characteristic of the EGSB reactor in the microaerobic conditions [J]. Acta Scientiae Circumstantiae, 2006, 26(2):220 - 224. (in Chinese)

[5] Dong Chunjuan, Lü Bing-nan, Chen Zhi-qiang. Characteristic of anaerobic granular sudge and digestionsludge under microaerobic conditions[J]. Journal of Nanjing University of Science and Technology, 2005, 29(2):216 - 222. (in Chinese)

[6] Lier J B, Rebac S, Lens P et al. Anaerobic treatment of partly acidified wastewater in a two-stage expanded granular sludge bed (EGSB) system at 8 ℃[J]. Water Science and Technology, 1997, 36:317 - 324.

[7] Ling Xuefeng, Zuo Jiane, Gu Xiasheng. Study on the operation of a methanogenic EGSB reactor under acid condition at pH 6.0[J]. Environmental Science, 2004, 1(1):57 - 61. (in Chinese)

[8] He Yanling. Anaerobic bio-treatment of wastewater[M]. Beijing: China Light Industry Press, 1998. (in Chinese)

[9] National Environmental Protecting Bureau. Detecting and analyzing method of water and wastewater[M]. 3rd ed. Beijing: China Environmental Science Publishing House, 1997. (in Chinese)

(**Editor:** Cai Jianying)