Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2019.24199

171 (2019) 57–61
December

Treatment of high-strength sulfate wastewater with EGSB reactor

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Received 18 October 2018; Accepted 14 January 2019

ABSTRACT

To investigate the feasibility of expanded granular sludge blanket (EGSB) reactor for the treatment of high-strength sulfate wastewater, the effect of EGSB reactor treating high-strength sulfate wastewater was investigated fed with xylose wastewater. Results showed that the EGSB reactor could be started up successfully in 21 d inoculated with anaerobic granular sludge when the influent chemical oxygen demand (COD)/SO_4^{2-} ratio was 3.5. The reactor showed a good performance during the steady-state period, when the loading rate was 21.6 kg COD m^{-3} d^{-1} and 6.2 kg SO_4^{2-} m^{-3} d^{-1}, respectively, the removal efficiency of COD was about 83%, SO_4^{2-} reduction rate was about 93%, the biogas production rate was 0.65 L g^{-1} COD, and the biogas yield was about 140 L d^{-1}.

Keywords: EGSB reactor; Xylose wastewater; Sulfate

1. Introduction

There are large amounts of high-strength sulfate organic wastewater were discharged in the production process of food, paper, medication, and so on. For high-strength organic wastewater, it is usually treated with anaerobic technology, which is not only economical and efficient but also produces methane that can be used. However, when the wastewater contains sulfates, during the anaerobic digestion process, the sulfate-reducing bacteria (SRB) will compete with methanogenic bacteria (MPB) for substrates and produce an inhibitory effect on MPB. Meanwhile, the sulfide produced by SRB reducing sulfates will also produce a toxic effect on MPB and reduces the treatment effect of the anaerobic reactor [1]. So the researchers used a two-phase process that separates the sulfate reduction process from the methanogens is processed to eliminate the effect of SRB on MPB, but which is costly due to the complexity of the process [2–8]. With the deepening research of SRB and the development of anaerobic reactors, some new high-efficiency anaerobic reactors have begun to be applied to the treatment of high-strength sulfate wastewater [9–13].

Expanded granular sludge blanket (EGSB) reactor is developed on the basis of the UASB reactor, compared with UASB reactor, the EGSB reactor added reflux, increased the flow velocity and enhanced mass transfer, and so EGSB reactor has high processing efficiency and operation stability, which has been widely used in wastewater treatment [14–18]. However, the application of high-strength sulfate wastewater treatment is still rare. This study intends to investigate the operating conditions and effect of EGSB reactor treating high-strength sulfate wastewater, which provides a reference for the application of the EGSB reactor in high-strength sulfate wastewater treatment.

2. Materials and methods

2.1. Reactor system

The EGSB reactor made of plexiglass with a working volume of 12.2 L (90 mm in diameter and 1,000 mm in height of the reaction zone, 190 mm in diameter and 250 mm in height of the precipitation zone). The temperature of the reactor was maintained at 35°C ± 1°C. The reactor system is shown in Fig. 1.

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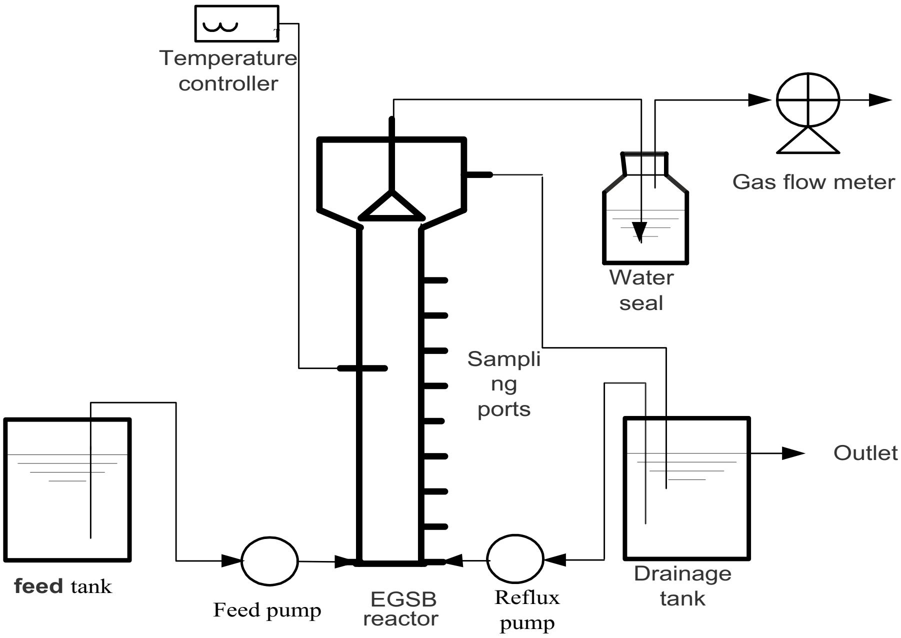

Fig. 1. Sketch of EGSB reactor system.

2.2. Materials

The wastewater is produced by the xylose production plant. The chemical oxygen demand (COD) concentration of wastewater is about 4,500 mg L^{-1}, the sulfate concentration is about 1,300 mg L^{-1}, and the pH value is about 7.0. The seed sludge of the EGSB reactor was taken from the internal circulation (IC) reactor of a citric acid producing plant. Granular sludge particle is 0.5–2 mm, the total suspended solid (TSS) and volatile suspended solid (VSS) were 109.06 and 78.52 g L^{-1}. The sludge concentration in the reactor was 25 g VSS L^{-1} after inoculation.

2.3. Experimental procedure

The experiment is divided into two stages: the reactor start-up stage and the stable operation stage. In the start-up stage, the load is gradually increased by controlling the influent flow and concentration. When the influent COD concentration reached 4,500 mg L^{-1} and the hydraulic retention time (HRT) reduced to 5 h, the start-up period of the reactor was over. During the stable operation period, the EGSB reactor run for 12 d at the constant loading rate, the treatment effect and operational stability of the EGSB reactor were investigated. In the process of operation, the reactor recirculation ratio was 10:1–25:1 according to the flow velocity (in 4 m h^{-1}) in the reactor.

2.4. Analytical methods

TSS, VSS, COD, and SO_4^{2-} were analyzed by standard methods [19-20]. pH was measured using a portable pH meter (Model HI9125), biogas production was measured by LML-1 wet gas flow meter (Model LML-1, Changchun Filter Co. Ltd., Changchun, China), biogas contents analyzed by gas chromatography.

3. Results and discussion

3.1. Start-up of the EGSB reactor

EGSB reactor started up after inoculating granular sludge with initial HRT of 10 h, and the influent COD concentration was about 2,000 mg L^{-1} through dilution, SO_4^{2-} concentration was about 580 mg L^{-1}, the loading rate was 4.8 kg COD m^{-3} d^{-1} and 1.4 kg SO_4^{2-} m^{-3} d^{-1}, respectively. When the COD removal efficiency exceeded 80%, the load increased gradually by shortening the HRT and increasing the influent COD concentration, the load increase rate was about 20% each time. On the 21st day, the influent COD concentration increased to 4,500 mg L^{-1}, the SO_4^{2-} concentration was 1,300 mg L^{-1}. Consequently, the loading rate reached 21.6 kg COD m^{-3} d^{-1} and 6.2 kg SO_4^{2-} m^{-3} d^{-1}. The COD removal rate reached 80.5%, the sulfate reduction rate reached 91.2%, and the reactor was successfully started.

It was found that the load increased too fast during the start-up process, it would cause acidification of the reactor, affecting the stable operation and treatment effect of the reactor [21]. In this test, the load increase rate was controlled to about 20%, and there was no acidification of the reactor during the start-up period, the effluent pH value of the reactor was 7.1–7.5. The changes in effluent pH are shown in Fig. 2. It can be seen that the load increasing scheme adopted was feasible and would not cause an adverse impact on the system.

3.2. Variation of COD

The variation of COD during the test is shown in Fig. 3. Due to the high activity of inoculated sludge, the COD removal rate reached 81.8% on the 6th day of operation.

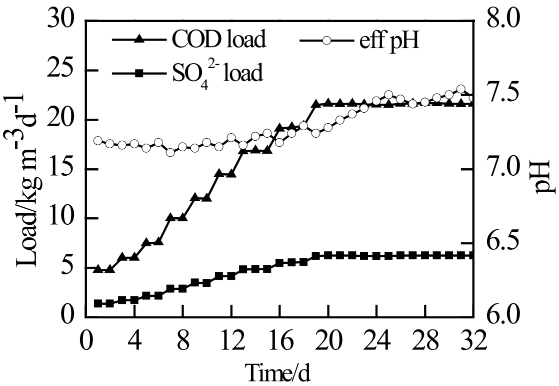

Fig. 2. Variation of effluent pH value with the load.

On the 9th day, the influent COD concentration was increased to about 3,000 mg L^{-1}, the loading rate was increased to 12 kg COD m^{-3} d^{-1}, and the COD removal rate decreased to 79.2%, but the COD removal rate recovered to over 80% after 1 d. On the 19th day, the influent COD concentration was increased to about 4,500 mg L^{-1}, and the loading rate was increased to 21.6 kg COD m^{-3} d^{-1}, 2 d later, the COD removal rate remained above 80%.

Yang et al. used a UASB reactor to treat xylose production wastewater when the loading rate was 3.6 kg COD m^{-3} d^{-1}, the COD removal rate was about 60% [22]. However, when the loading rate of the EGSB reactor used in this test reached 21.6 kg COD m^{-3} d^{-1}, the COD removal rate could still be maintained at about 80%, indicating that the EGSB reactor has a good treatment effect on high sulfate wastewater.

3.3. Variation of SO_4^{2-}

Variation of SO_4^{2-} during the test is shown in Fig. 4. At the initial stage of start-up, the influent SO_4^{2-} concentration was about 580 mg L^{-1}, and the SO_4^{2-}reduction rate was about 83%. With the increase of sludge activity and sludge concentration, the SO_4^{2-} reduction rate gradually increased, when the influent SO_4^{2-} concentration was gradually increased to about 1,300 mg L^{-1}, the effluent SO_4^{2-} concentration was about 90 mg L^{-1}, and the SO_4^{2-} reduction rate reached 93%.

Studies have shown that whether SRB has an inhibitory effect on MPB depends mainly on the COD/SO_4^{2-} the value of the influent [23–27]. Yang et al. found that when the COD/SO_4^{2-} the value of xylose production wastewater was over 2.78, SRB would not inhibit MPB [28]. In this experiment, the COD/SO_4^{2-} value was maintained at about 3.5, the SRB and MPB in the system were in a relatively balanced state, both of the SRB and MPB had higher activity, which made COD and SO_4^{2-} achieve better removal effect.

3.4. Variation of the biogas production rate and biogas yield

With the operation of the reactor, the sludge activity gradually increased, and the biogas production rate and biogas yield gradually increased (Fig. 5). After 13 d, the biogas production rate was maintained at 0.55–0.65 L g^{-1}

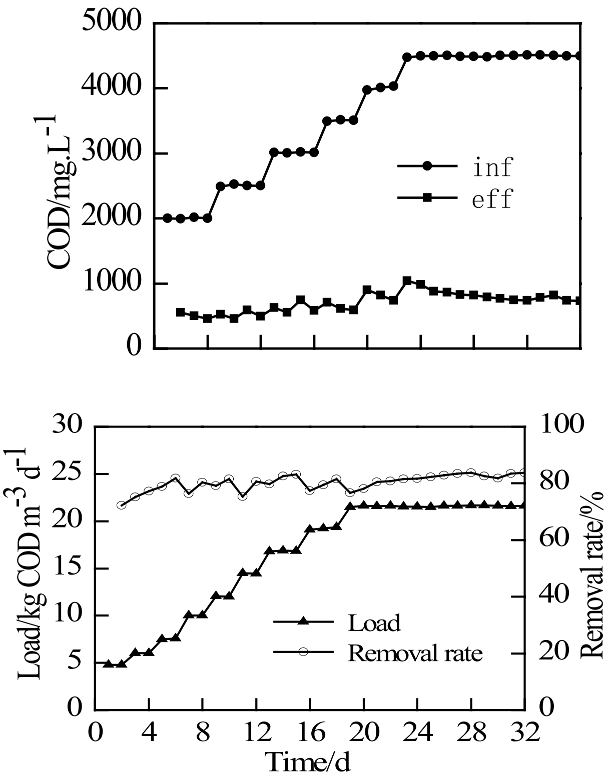

Fig. 3. Variation of COD.

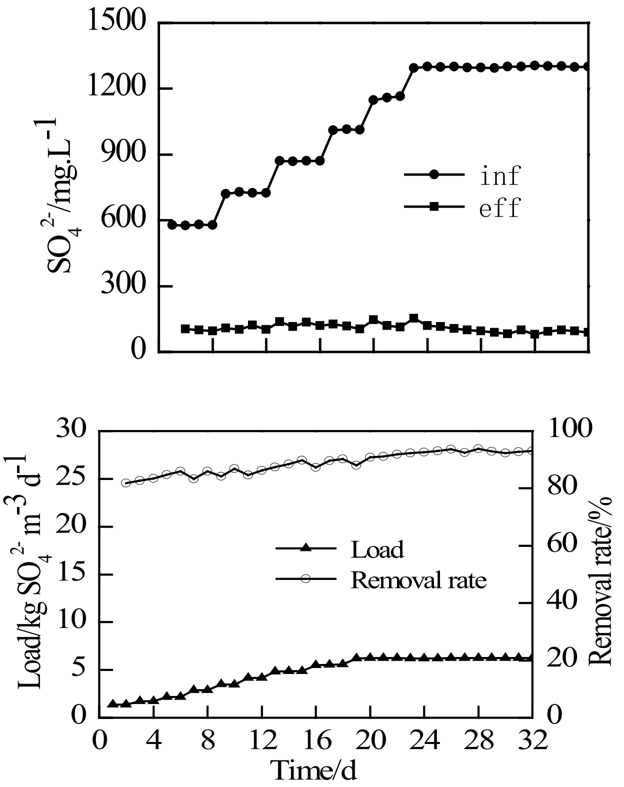

Fig. 4. Variation of SO_4^{2-}.

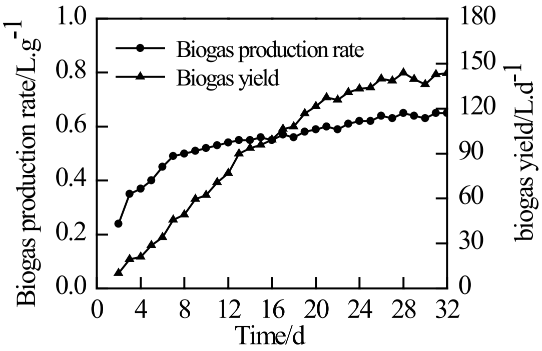

Fig. 5. Variation of the biogas production rate and biogas yield.

Table 1
Components of biogas

Component (%)	Day 7	Day 14	Day 21
CH_4	65.23	70.81	73.56
CO	1.50	1.44	1.36
CO_2	12.77	11.53	11.52
N_2	0.65	2.72	2.86
H_2S	0.37	0.25	0.22

COD, the biogas yield increased with the increase of load. During the steady operation period, the biogas yield reached about 140 L d^{-1}.

The gas components at different stages were monitored during the test, as shown in Table 1. It can be seen that in the early stage of the test, the CH_4 content in the biogas is 65.23%. With the increase of the influent concentration and load, the CH_4 content in the gas also rise to over 70%. The content of H_2S in the biogas is below 0.5%, and the concentration is low, which had no toxic effects on methanogens.

4. Conclusion

Using xylose production wastewater, inoculation of anaerobic granular sludge, maintaining the influent COD/SO_4^{2-} value of about 3.5, the loading rate increase rate is controlled at about 20% each time, and the EGSB reactor was successfully started up in 21 d. The EGSB reactor has a good removal effect on high-strength sulfate wastewater. When the loading rate was 21.6 kg COD m^{-3} d^{-1} and 6.2 kg SO_4^{2-} m^{-3} d^{-1}, the COD removal rate was about 83% and the sulfate reduction rate was about 93%. The biogas yield increased with the increase of load. During the steady operation period, the biogas production rate was maintained at 0.65 L g^{-1} COD, and the biogas yield was about 140 L d^{-1}.

References

[1] P.N.L. Lens, J.G. Kuenen, The biological sulfur cycle: novel opportunities for environmental biotechnology, Water Sci. Technol., 44 (2001) 57–66.
[2] Y. Maspolim, Y. Zhou, C.H. Guo, K. Xiao, W.J. Ng, Comparison of single-stage and two-phase anaerobic sludge digestion systems – performance and microbial community dynamics, Chemosphere, 140 (2015) 54–62.
[3] G. Randrianarison, M.A. Ashraf, Microalgae plant (*Chlorella* sp.) for wastewater treatment and energy production, Ekoloji, 27 (2018) 1455–1465.
[4] M.M. Hanafiah, N.A. Hashim, S.T. Ahmed, M.A. Ashraf, Removal of chromium from aqueous solutions using a palm kernel shell adsorbent, Desal. Wat. Treat., 118 (2018) 172–180.
[5] Y.Y. Li, Y.Y. Jin, Effects of thermal pretreatment on acidification phase during two-phase batch anaerobic digestion of kitchen waste, Renewable Energy, 77 (2015) 550–557.
[6] G.T. Patle, T.T. Sikar, K.S. Rawat, S.K. Singh, Estimation of infiltration rate from soil properties using regression model for cultivated land. Geol. Ecol. Landscapes, 3 (2019) 1–13.
[7] C.-H. Wei, W.-X. Wang, Z.-Y. Deng, C.-F. Wu, Characteristics of high-sulfate wastewater treatment by two-phase anaerobic digestion process with jet-loop anaerobic fluidized bed, J. Environ. Sci.-China, 19 (2007) 264–270.
[8] J. Lindner, S. Zielonka, H. Oechsner, A. Lemmer, Effect of different pH-values on process parameters in two-phase anaerobic digestion of high-solid substrates, Environ. Technol., 36 (2015) 198–207, 331–333.
[9] H. Normah, M.J. Hanapi, Antioxidant capacity of the green leafy vegetables using oxygen radical antioxidant capacity (Orac), 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid (Abts) and 2,2-diphenyl-1-picrylhydrazyl (Dpph) assays, Sci. Heritage J., 3 (2019) 1–7.
[10] M. Vossoughi, M. Shakeri, I. Alemzadeh, Performance of anaerobic baffled reactor treating synthetic wastewater influenced by decreasing COD/SO_4 ratios, Chem. Eng. Process., 42 (2003) 811–816.
[11] S. Venkata Mohan, N. Chandrasekhara Rao, K. Krishna Prasad, P.N. Sarma, Bioaugmentation of an anaerobic sequencing batch biofilm reactor (AnSBBR) with immobilized sulphate reducing bacteria (SRB) for the treatment of sulphate bearing chemical wastewater, Process Biochem., 40 (2005) 2849–2857.
[12] S. Qian, The damping loss prevention research on aerobics special shoe materials based on intelligent analysis, Sci. Heritage J., 3 (2019) 20–23.
[13] J. Weijma, E.A.A. Bots, G. Tandlinger, A.J.M. Stams, L.W. Hulshoff Pol, G. Lettinga, Optimization of sulfate reduction in a methanol-fed thermophilic bioreactor, Water Res., 36 (2002) 1825–1833.
[14] C. Fang, S.P. O-Thong, K.W. Boe, I. Angelidaki, Comparison of UASB and EGSB reactors performance, for treatment of raw and deoiled palm oil mill effluent (POME), J. Hazard. Mater., 189 (2011) 229–234.
[15] T.D.T. Oyedotun, L. Johnson-Bhola, Beach litter and grading of the coastal landscape for tourism development in sections of Guyana's Coast, J. CleanWAS, 3 (2019) 1–9.
[16] L.W. Hulshoff, S.I. de Castro Lopes, G. Lettinga, Anaerobic sludge granulation. Water Res., 38 (2004) 1376–1389.
[17] J.Y. Liu, J. Hu, J.P. Zhong, J.H. Luo, A.H. Zhao, F. Liu, R.J. Hong, G.R. Qian, Z.P. Xu, The effect of calcium on the treatment of fresh leachate in an expanded granular sludge bed bioreactor, Bioresour. Technol., 102 (2011) 5466–5472.
[18] D. Zhang, Z. Verstraete, The anaerobic treatment of nitrite containing wastewater using an expanded granular sludge bed (EGSB) reactor, Environ. Technol., 22 (2001) 905–913.
[19] A. Samsudin, M.A.A. Samah, M.Y. Ishak, Perception of government servants in shah alam on the utilization of food waste as a resource for biogas production in Malaysia, J. CleanWAS, 3 (2019) 16–20.
[20] APHA, AWWA, WPCF, Standard Methods for the Examination of Water and Wastewater, 19th ed., American Public Health Association, American Water Works Association and Water Pollution Control Federation, New York, 1995.
[21] L.J. Wang, W.H. Zheng, X.S. Shi, Analysis on acidification reason of IC reactor and restart, China Water Wastewater, 23 (1997) 95–97.
[22] Y.J. Yang, B. Zhu, G. Fan, Xylose wastewater treatment, Water & Wastewater Eng.-China, 25 (1999) 39-42.

[23] O.T. Joseph, O.O. Adeoti, A.A. Olufemi, Study of the phytodiversity along Antorun Reservoir, near Ogbomoso, Nigeria, Environ. Ecosyst. Sci., 3 (2019) 1–12.
[24] E. Choi, J.M. Rim, Competition and inhibition of sulfate reducers and methane producers in anaerobic treatment, Water Sci. Technol., 23 (1991) 1259–1264.
[25] M. Wilson, M.A. Ashraf, Study of fate and transport of emergent contaminants at waste water treatment plant, Environ. Contam. Rev., 1 (2018) 1–12.
[26] A. Visser, L.W. Hulshoff Pol, G. Lettinga, Competition of methanogenic and sulfidogenic bacteria, Water Sci. Technol., 33 (1996) 99–110.
[27] A.P. Annachhatre, S. Suktrakoolvait, Biological sulfate reduction using molasses as a carbon source, Water Environ. Res., 73 (2001) 118–126.
[28] J.X. Yang, Z.S. Li, J. Xie, Effect of sulfate on anaerobic treatment of xylose wastewater, China Biogas, 19 (2011) 19–22.