Journal of Environmental Science and Engineering A 6 (2017) 243-248
doi:10.17265/2162-5298/2017.05.003

The Effect of Non-acidified Wastewater on Expanded Granular Sludge Bed (EGSB) Reactors Performance

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Abstract: The textile processing plants utilize a wide variety of dyes and other chemicals such as acids, bases, salts, detergents, sizes, oxidants, mercerizing and finishing chemicals. Many of these are not retained in the final product and are discharged in the effluent. Therefore, the objective of this study was to assess the performance of EGSB (Expanded Granular Sludge Bed) reactor to treat non-acidifie wastewater. Several experiments using starch and volatile fatty acids as model substrates were conducted. The problems of piston formation were evaluated at a variety of relevant operational conditions, such as substrate concentration, organic and hydraulic loading rates. The results showed that newly grown acidogenic biomass diluted original methanogenic biomass and the granular sludge in the EGSB reactor deteriorated. The piston formation in the EGSB reactor that was fed with non-acidified wastewater occurred due to high growth of acidogenic biomass and high upflow velocity applied in the system.

Key words: Non-acidified wastewater, starch wastewater, EGSB (Expanded Granular Sludge Bed).

1. Introduction

The textile wet processing industry uses large quantities of water. Due to the variety of process steps and chemicals involved, the various water streams which occur in a textile factory vary greatly with regard to their nature and the concentration of the different constituent. Desizing process generates a large amount of starch-containing wastewater. It can account for 20-30% of COD (Chemical Oxygen Demand) in total effluent.

The starch is hydrolyzed to hexoses or pentoses by the exoenzyme of the acidification bacteria. The most important end products of the fermentations are: formic acid, acetic acid, propionic acid, butyric acid, lactic acid and ethanol. Besides the above products, there are other products possible such as valeric acid, caprovic acid, aldehydes and ketones. It depends on the type of fermentation.

In an effort to design a cheap and effective bioremediation system for textile industry, an anaerobic system can be used to at least partially treat these effluents and provide a number of significant advantages.

For many years, the benefits and the drawbacks of EGSB (Expended Granular Sludge Bed) reactor have been the subject of discussion. With the use of effluent recirculation, liquid upward velocities exceeding 5 to 6 m/h can be achieved, which is significantly higher than the 0.5 to 1.5 m/h range generally applied for UASB (Upflow Anaerobic Sludge Blanket) reactor [1-3]. This modification can improve wastewater-biomass contact during anaerobic treatment by the expanding sludge bed and intensifying the hydraulic mixing which enhances the penetration of substrate into the biofilm.

So far, little information is available about the influence of non-acidified starch to the process stability and the granule quality in EGSB reactors [4, 5].

For non-acidified substrates, the developed biomass is very likely to consist of an important fraction of acidogenic bacteria. The amount of biomass

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developing in the reactor will depend on the yield and decay rates of the anaerobic bacteria involved, and consequently on the applied loading rate and the sludge retention of the system.

The objective of this study was to assess the effect of non-acidified substrates and partially-acidified substrate on the performance of the EGSB reactor.

Several experiments using soluble modified starch and volatile fatty acids as model substrates were conducted. The problems of degration of soluble modified starch were evaluated at a variety of relevant operational conditions, such as substrate concentration, starch and volatile fatty acid ratio, and organic and hydraulic loading rates. Additionally, some solutions were proposed to improve the sludge quality and increase the treatment efficiency of the system.

2. Material and Method

2.1 Reactors

Experiments were performed using a 0.05 m diameter glass EGSB reactor with total volume 4.3 L (settler included). All equipments were described by Lang, T. T. [6].

2.2 Biomass

The reactors were inoculated with granular sludge that was obtained from a full scale UASB reactor treating the effluent of a potato-processing factory. The total amount of granular sludge added at the start up was approximately 15 g VSS/L for each reactor.

2.3 Medium

In the first period, the reactor was fed with soluble modified starch from textile industry. 1 g solid starch was dissolved in 1 L of demiwater containing 1 g of $NaHCO_3$. Then it was stored in the refrigerator to prevent acidification.

In the second period, the reactor was fed with a concentrated stock solution of 30.0 g $COD{\cdot}L^{-1}$. The substrate consisted of a partly neutralized (pH = 6.5) VFA (Volatile Fatty Acid) mixture composed of acetate, propionate and butyrate in the ratio 1:1.5:1.8, based on COD.

The concentrations of basal nutrient in the concentrated stock solution were presented by Lettinga, G. [2].

Feeding of the reactor was started immediately after inoculation with the mesophilic granular sludge at an OLR (Organic Loading Rate) of 2.2 g $COD{\cdot}L^{-1}{\cdot}d^{-1}$ and a HRT (Hydraulic Retention Time) of 13.4 h. From the start of the experiment, the temperature of the reactor was set at 30 ^{o}C. During the continuous operation of the reactor, the samples of influent and effluent were taken three times per week in duplicate.

3. Analyses

3.1 Starch

The determination of starch was carried out by using SIC (Starch-iodine Complex Formation) method [7].

3.2 Volatile and Total Suspended Solids

Volatile and total suspended solids of sludge were determined according to standard methods [7].

4. Results

4.1 Reactor Performance

The operational conditions and efficiency of the EGSB reactor system are summarised in Table 1. The system was fed only with modified starch in the period I (days 0-37). In the period II (days 38-115), the system was supplied with VFA (acetate: propionate: butyrate = 1:1.5:1.8 based on COD).

4.2 The Performance of the EGSB System Fed only with Starch

The performance data of the EGSB system in the period (days 0-37) are presented in Fig. 1. The system operated under two conditions at HRT 13 h and correspondingly OLR of 2 g $COD{\cdot}L^{-1}{\cdot}d^{-1}$ (days 0-15) and in the period (days 15-37) at HRT 5 h and OLR of

Table 1 Operational condition and the performance of EGSB reactor.

Period	T	Substrate	HRT	OLR	Efficiency (%)	
(day)	(°C)		(hour)	(g COD·L^{-1}·day^{-1})	COD	CH_4-COD
0-15	30	Starch	13.0	2.0	85-90	45-50
16-37	30	Starch	5.0	4.0	70-80	15-20
38-45	30	VFA	5.0	10.0	70-90	30-60
46-60	30	VFA	2.0	10.0	70-90	60-70
61-87	30	VFA	1.2	15.0-20.0	80-95	65-80
88-115	30	VFA	1.2	20.0	> 95	60-70

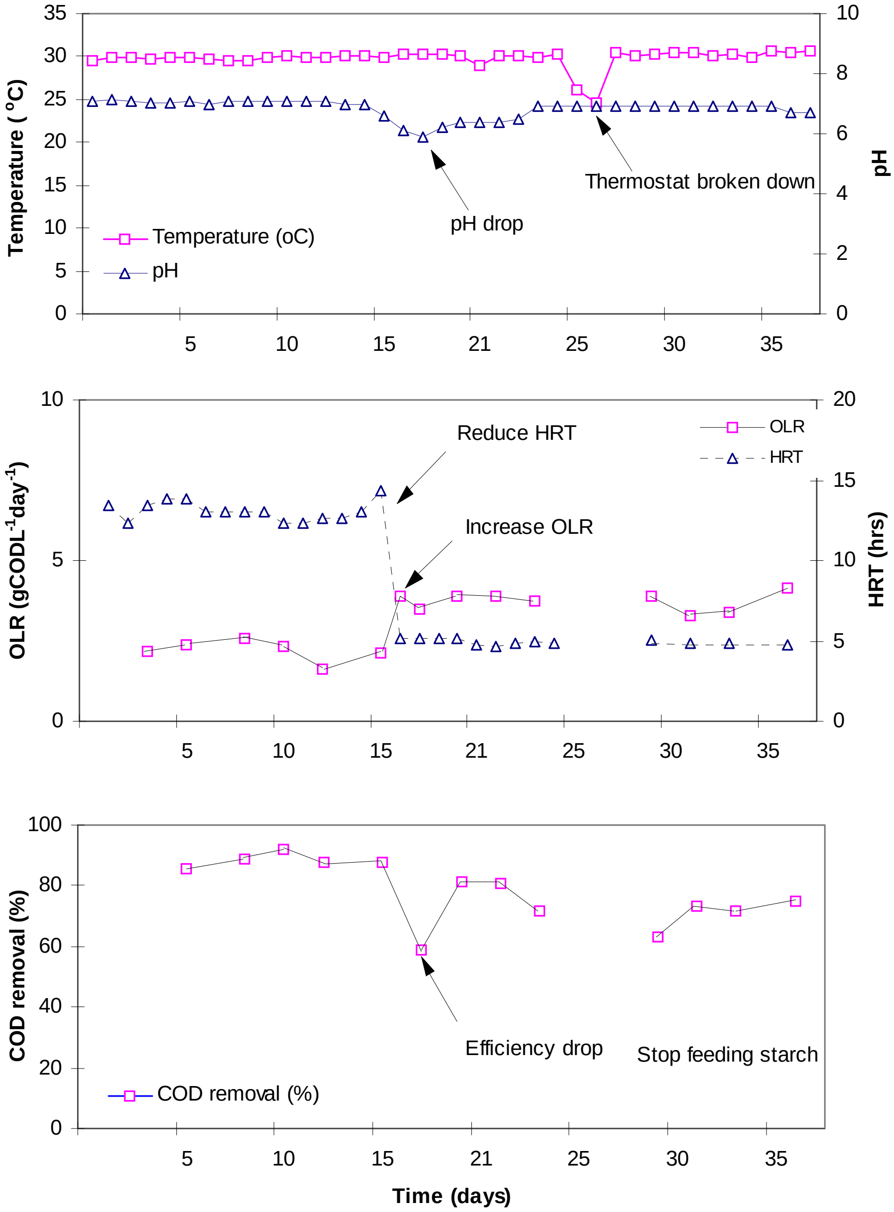

Fig. 1 pH, temperature, OLR, HRT and COD removal of EGSB reactor from day 0 to day 37 (supplied with starch).

4 g COD·L^{-1}·d^{-1} (Fig. 1).

The EGSB system (period days 0-15) had high removal efficiency of 85-90% (Fig. 1), which could be attributed to low load and the fact that modified starch already partly pre-acidified prior entering the EGSB reactor. The fermentation of the starch in all this period was in the range 90-95%, which resulted in the high yield of acidogenic biomass in the EGSB reactor. The high yield of acidogenic biomass was manifested throughout significant increase of the height of the sludge bed. In order to prevent strong wash-out of biomass from the EGSB reactor, significant amount of 325, 287 and 103 g wet sludge had to be withdrawn from the reactor on days 8, 14 and 18, respectively.

The day after the OLR was increased from 2 to 4 g COD·L^{-1}·d^{-1} (day 17), and pH in the reactor dropped to 5.9 due to insufficient buffer capacity, as more bicarbonate was needed to be supplied to the system. When pH dropped, the removal efficiency of the EGSB reactor shortly dropped from 85 to 60% (Fig. 1).

The hig filamentous sludge production in the reactor was continued that the reactor was completely full with biomass (day 25, Fig. 1), when the system was switched to recycle mode for two days without feed of starch.

The height of the acidogenic biomass bed was reduced from 120 to 30 cm in these two days. After the feed of starch was resumed on day 27, the sludge bed height was increased up to 120 cm again within 3 days. This indicates that hold up of acidogenic sludge in the reactor under EGSB conditions (upflow velocity of 6-10 m·h^{-1}) was very difficult.

4.3 The Degradation of Starch Plus VFA Mixture in EGSB Reactors

A very high fermentation of starch was obtained in period days 28 to 36. The starch fermented more than 95% when acidogenic sludge was prevalent in the reactor. In the remaining period, amount of starch fermented was in the range of 87 to 92%. It is easy to see at the high starch fermentation period (from day 28 to 37), there exists a reduction of COD removal efficiency apparant. This indicates that acidogenic biomass promotes the fermentation process of starch, leading a low activity of methanogenic bacteria. Consequencely, the COD removal efficiency drops. Aside from the decreased treatment performance, the quick development of acidogenic sludge also resulted in a distinct effluent composition. Propionate and acetate were detected together in higher amounts with a small amount of starch in the effluent, when comparing with the former period.

4.4 Piston Formation

Sludge piston formation occurred at day 4. Sludge piston formation was observed when a poor sludge bed expansion occurred at low liquid upflow velocity.

A minimum V_{up} of 2.5 m·h^{-1} is required to prevent the sludge piston formation [8]. In the first period, authors applied an upflow velocity of 6 m·h^{-1}, but piston formation was occurred. The small diameter of the laboratory-scale reactor likely significantly contributed to this problem [9]. The dense unexpanded sludge bed causes considerable gas entrapment at the bottom of the reactor. When the buoyancy of the accumulated gas is high enough, there is an incidental flotation of part of the sludge bed as a piston. The observation of authors' experiments indicates that the quick development of acidogenic biomass can be considered the main reason [9]. They can attach to granular sludge together to increase the density of sludge, diminish the expansion of the sludge bed, obstruct the gas at the bottom and form the piston. To overcome that problem, authors decided to increase upflow velocity to 10 m·h^{-1} at the day 5 by increasing the recirculation rate. This upflow velocity was kept from 10 to 11 m·h^{-1} until the end of this experiment. However, increasing upflow velocity caused another problem. It increased the dispersed acidogenic biomass on the top of the reactor and sludge washes out easily.

4.5 The Treatment Efficiency in the EGSB Reactor

The treatment efficiency was assessed in relation to the imposed hydraulic and organic loading rate. During the first periods of the experiments (day 0 to 37), when the reactor was fed with starch at COD_{in} level ranging 800 to 1,200 mg COD·L^{-1}, a high treatment performance with COD removal efficiency exceeding 90% was obtained at OLRs up to 2.3 g COD/L·d and exceeding 80% at OLRs up to 3.9 g COD/L·d. The treatment efficiency ultimately dropped due to the fact that substantial amount not only because of the acidogenic biomass prevailed in the reactor and to the fact that but also because of a large amount of sludge want to be discharged in order to prevent sludge washout.

4.6 The Performance of the EGSB System Fed with VFA

The performance data of the EGSB system in the period (days 38-115) are presented in Fig. 2 and sumerized in Table 1. The system operated under three conditions at HRT 5 h and OLR of 10 g COD·L^{-1}·d^{-1} (days 38-45), at HRT 2 h and OLR of 10 g COD·L^{-1}·d^{-1} (days 46-60), and at HRT 1.2 h and OLR of 15-20 g COD·L^{-1}·d^{-1} (days 61-115) (Fig. 2).

The removal efficiencies of EGSB system were 70-90%, 70-80% and 80-95% in periods days 38-45, days 46-60 and 61-115, respectively (Fig. 2, Table 1).

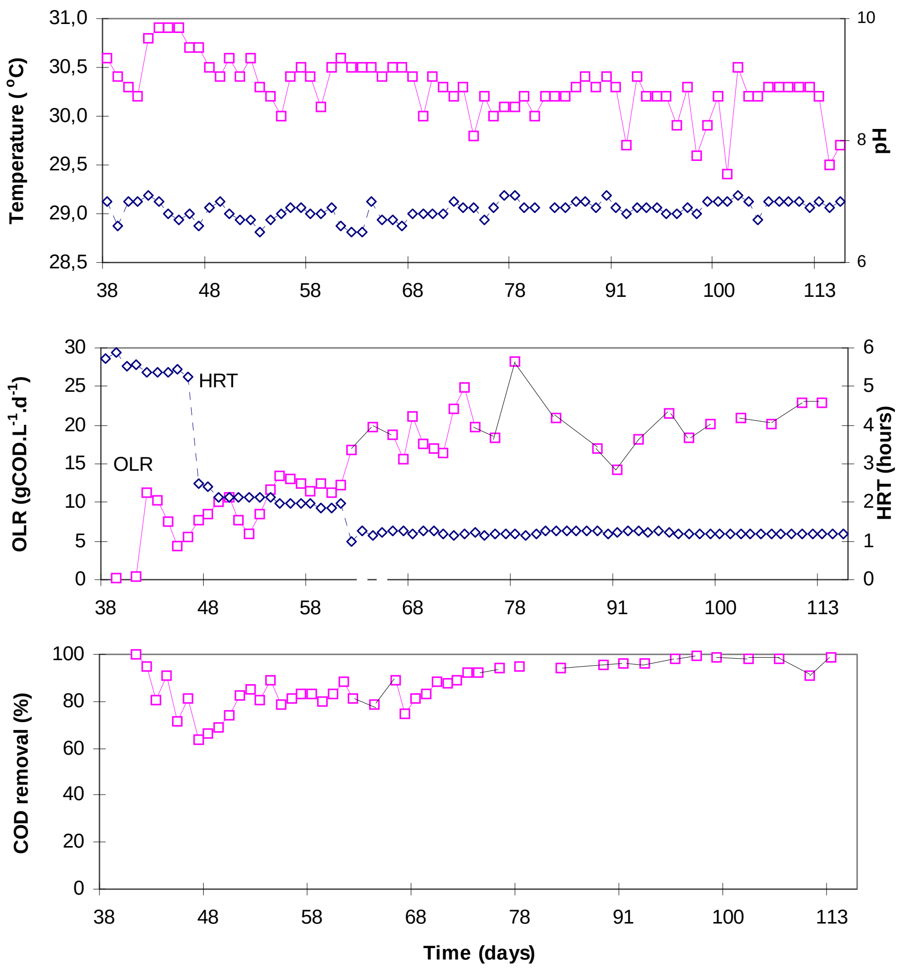

Fig. 2 Temperature, pH, OLR, HRT, COD removal (%) of EGSB reactor in the second period (days 38-115).

This results reveal very high potentials of EGSB reactor as high-rate system for anaerobic treatment of low strength acidified wastewaters (in the range 900-1,000 mg COD·L^{-1}) under mesophilic conditions. After day 88, the removal efficiency was > 95%, which indicates that the EGSB system could be loaded even more. The EGSB system showed some problems in propionate removal in the period days 38-80, but later propionic acid, which is known as the most difficult VFA intermediate during methanogenic anaerobic degradation, was well removed. The high removal efficiencies were achieved at low influent concentration applied.

5. Conclusion

Non-acidified substrate (modified starch) strongly affects degradation of volatile fatty acids to methane;

Newly grown acidogenic biomass diluted original methanogenic biomass and the granular sludge in the EGSB reactor deteriorated;

The hold up of biomass in the EGSB reactor when was fed with non-acidified wastewater was very difficult due to high growth of acidogenic biomass and high upflow velocity applied in the system;

The EGSB system showed high feasibility as high-rate anaerobic system under mesophilic conditions when was fed with acidified wastewater.

Recommendation

Research on development of a high-rate acidification reactor (HRT << 4 h) needs to be carried out;

Use of packing material for the hold-up of acidogenic biomass in an acidifying reactor needs further research.

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