Post-treatment of UASB effluent in an expanded granular sludge bed reactor type using flocculent sludge

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Abstract The performance of an EGSB (expanded granular sludge bed) reactor type using flocculent sludge was evaluated for the post-treatment of effluent from UASB reactor treating domestic sewage. A pilot-scale 157.5-L EGSB reactor was monitored during a 331-day period. The original concept of the EGSB reactor was based on granular sludge use and by applying of high upflow liquid velocities (V_{up}). However, even using flocculent sludge from a UASB full-scale (Mangueira Plant, Recife, Brazil), good mixing conditions and high retention of biomass were achieved. By applying a 4-h hydraulic retention time and V_{up} values up to 3.75 m/h, effluent chemical oxygen demand concentrations in the EGSB were below 87 mg/L and 55 mg/L, for total and filtered samples, respectively. Total suspended solid (TSS) concentrations in the effluent were below 32 mg/L. Good performance and stable reactor operation during the whole experimental period were observed. Therefore, the EGSB reactor type using flocculent sludge can also be used for post-treatment of very dilute anaerobic effluent from reactors treating domestic sewage.

Keywords Anaerobic effluent; domestic sewage; EGSB reactor; flocculent sludge; post-treatment; remaining COD removal

Introduction

The expanded granular sludge bed reactor (EGSB) was developed to overcome problems such as preferential flows, hydraulic short cuts and dead zones that can occur in the upflow anaerobic sludge bed reactor (UASB). By using granular sludge in a EGSB reactor, liquid upflow velocity (V_{up}) up to 10 m/h can be achieved, in contrast with the 0.5–1.5 m/h values applied in UASB reactors. The higher V_{up} in EGSB reactors can be achieved by using adequate height/diameter ratio or effluent recirculation. The increase of V_{up} improves the sludge bed expansion and the bulk mixture to promote better biomass-substrate contact (Kato, 1994; van Lier *et al.*, 1997). As a consequence, high biogas production is achieved that will result in an additional mixture improvement to the reactor. Due to the hydrodynamic characteristics in the EGSB reactor, special attention should be paid to the design of solids separation device in order to prevent biomass washout in the effluent, which would result in a drop of reactor efficiency (Kato *et al.*, 1999).

So far the EGSB reactor with granular sludge has been applied to treat wastewaters predominantly soluble and of low strength, although complex and high concentrated wastewaters can also been treated. During the treatment of slaughterhouse wastewater, 67% of chemical oxygen demand (COD) was removed when 15 kg COD/m^3.d of volumetric organic loading rate (OLR) was applied (Nüñez and Martinez,1999); and for low strength ethanol wastewater (100 to 200 mg COD/L) by applying OLR up to 12 kg COD/m^3.d, 80% COD removal efficiency was obtained (Kato, 1994). Good performance results were also observed in some studies concerning the application of granular sludge EGSB reactor for the treatment of different wastewaters (Kurisu *et al.*, 1997; Lettinga *et al.*, 1999).

However, the use of the EGSB reactor type has not extensively been studied for the post-treatment of UASB reactor effluents from municipal wastewater treatment plants. This can be attributed to the relatively high total suspended solids (TSS) concentration present in

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such effluents. Due to the high V_{up} values applied, it would be expected that EGSB wouldn't be efficient to remove TSS. Additionally, it is usual that a seed granular sludge be needed to start up the EGSB reactor. However, the anaerobic sludge developed in UASB treating municipal wastewater is predominantly flocculent. Wang *et al.* (1997) studied the application of EGSB reactor type for post-treatment of an upflow hydrolytic reactor treating municipal wastewater. For temperatures above 15°C, efficiencies up to 70% and 83% for COD and TSS, respectively, were obtained for the combined reactors. For a temperature of 12ºC and hydraulic retention time (HRT) of 5 h, the COD and TSS removal efficiency dropped to 51% and to 76%, respectively.

Preliminary short-term experiments with 9 phases of approximately 30 days each, indicated that EGSB reactor, seeded with flocculent sludge, could be used for post-treatment of UASB reactor treating municipal wastewater (Vieira *et al.*, 2000). When HRT from 2 to 4 h and V_{up} values from 1.25 m/h to 7.63 m/h were applied, the removal efficiencies reached values from 62 to 74% for COD, and 45% to 92% for volatile suspended solids (VSS). The objective of this work was to evaluate during a long-term period, the performance of an EGSB pilot reactor using flocculent sludge for the post-treatment of effluent from a UASB full-scale reactor treating municipal wastewater.

Methods

The experimental work was carried out in a pilot EGSB reactor (20 cm inner diameter, PVC tube coated externally with fiber glass) fed with the effluent from a full-scale UASB (810 m^3) treating municipal wastewater (Mangueira Plant, Recife, Brazil). The reactor height and volume were 5 m and 157.5 L, respectively. A settler (fiber glass) was installed in the upper part and had a height and volume of 1 m and 243.5 L, respectively. Along the reactor height 10 taps were installed in order to collect samples for the sludge profile measurement. Methane production was measured in a wet gas meter after biogas passed in a 7.5% NaOH solution. The scheme of the reactor system is shown in Figure 1. Monitoring was followed in three different phases by varying the V_{up} values according to Table 1. HRT was set at 4 h in all the experimental phases. The reactor was seeded with 4.6 g VSS/L of flocculent sludge from the same full-scale UASB reactor. Average values of influent COD and suspended solids are shown in Table 2. Samples in the influent and effluent were collected usually three times a week. Filtered COD and suspended solids were obtained by using 1.2 μm and 0.45 μm filters, respectively. The COD removal efficiency was calculated based on the difference between total influent and effluent COD (total COD efficiency) or total influent COD and filtered effluent COD (filtered COD efficiency). All analyses were conducted according to the *Standard Methods* (APHA/AWWA/WEF, 1995).

Results and discussion

The average values of the effluent characteristics and operational parameters are shown in Table 3. Figures 2, 3 and 4 illustrate the influent and effluent COD concentrations, the COD removal efficiency, and TSS and VSS effluent concentrations, respectively.

The results shown in Table 3 and Figures 2 and 3 demonstrate that there was no significant difference in COD removal efficiency during the three experimental phases. This

Table 1 EGSB reactor operational conditions

Phase (HRT = 4 h)	Influent flow (L/h)	Recirculation flow (L/h)	V_{up} (m/h)
1 (0 to 113 day)	39.375	0.000	1.25
2 (114 to 206 day)	39.375	39.375	2.50
3 (207 to 331 day)	39.375	78.750	3.75

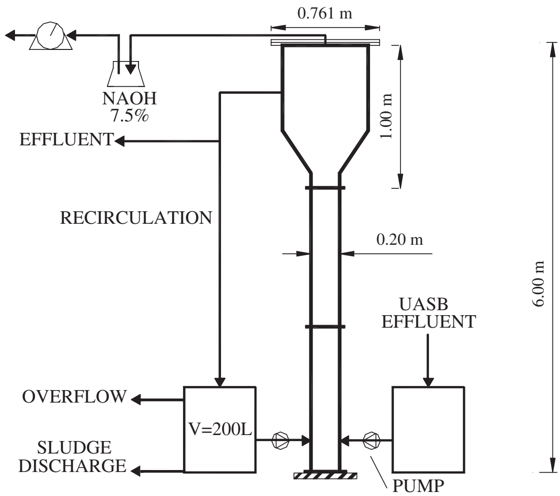

Figure 1 Schematic figure of the pilot EGSB reactor system

Table 2 Influent average values of the pilot EGSB reactor

Phase	Temperature (°C)	pH	Total COD (mg/L)	Filtered COD (mg/L)	TSS (mg/L)	VSS (mg/L)
1 (0 to113 day)	29.7 ± 1.7	6.9 ± 0.1	126 ± 53	56 ± 22	94 ± 68	42 ± 27
2 (114 to 206 day)	30.3 ± 2.0	6.7 ± 0.2	180 ± 50	79 ± 31	115 ± 67	54 ± 29
3 (207 to 331 day)	32.0 ± 1.9	6.9 ± 0.2	156 ± 48	55 ± 19	123 ± 70	63 ± 30

Table 3 Effluent average characteristics and operational parameters

Phase	V_{up} (m/h)	COD (mg/L)		COD removal efficiency (%)		TSS (mg/L)	VSS	
		Total	Filtered	Total	Filtered		(mg/L)	Rem. (%)
1	1.23 ± 0.01	68 ± 29	42 ± 21	43	65	18 ± 10	13 ± 8	63
2	2.47 ± 0.03	87 ± 21	55 ± 22	48	68	11 ± 4	8 ± 3	82
3	3.83 ± 0.06	79 ± 26	44 ± 15	48	70	32 ± 21	24 ± 17	59

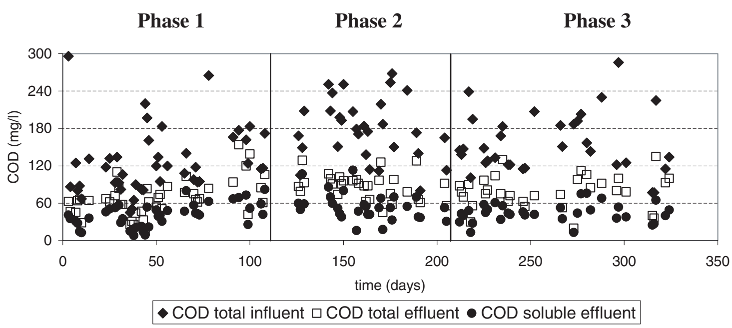

Figure 2 Influent and effluent COD concentrations

indicates that the 4-hour HRT applied, which is already relatively low for domestic sewage treatment, even in the case of post-treatment, represents a considerable advantage for the EGSB reactor type. Such an aspect is important if considering the use of flocculent sludge in the EGSB reactor and the applied V_{up} values up to 3.83 m/h. Average values of COD in the effluent during the three phases were below 87 mg/L and 55 mg/L for total and filtered

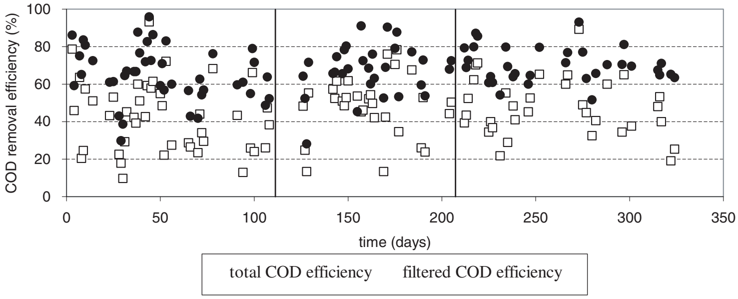

Figure 3 COD removal efficiency

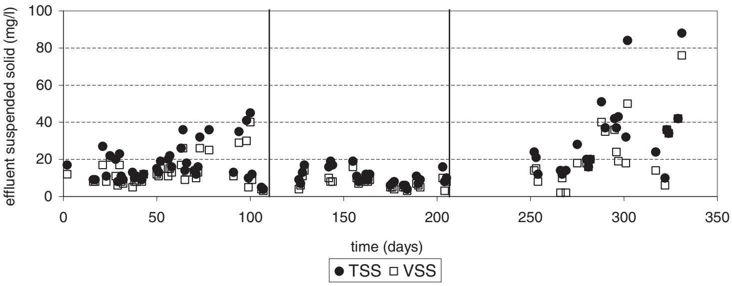

Figure 4 Effluent TSS and SSV concentrations

samples, respectively. In some Brazilian states, environmental agencies recommend a limit of 90 mg COD/L for effluent discharge. The higher V_{up} values applied in this experiment, compared with those used in UASB reactors, is an important factor because of the influent COD values of less than 200 mg/L resulting in low COD in the effluent. Based on the total and filtered effluent COD, efficiencies were 48% and 70%, respectively.

Considering the seed sludge from domestic sewage, the good COD removal efficiency results can also be attributed to the relatively high methanogenic activity. A value of 0.2 g COD/g VSS.d was determined previously (Florencio *et al.*, 2001). The fact that there was no significant difference in the COD removal efficiency by applying three different V_{up} values can be explained by the low sludge loading rate (SLR) applied in the three phases, due to the low COD concentrations in the influent. An average value of 12 g VSS/L reactor obtained by the sludge profile measurement during the experimental phases resulted in SLR of only 0.1 g COD/g VSS.d or lower. Values of OLR applied were 1.4 g COD/L.d.

The results shown in Table 3 and Figure 5 reveal that values of TSS and VSS were below 32 mg/L and 24 mg/L, respectively. These values can be considered as very satisfactory, since some Brazilian environmental agencies in general recommend 60 mg/L of TSS for effluent discharge. No significant difference was observed between phase 1 and phase 2, when V_{up} values measured were 1.23 m/h and 2.47 m/h, respectively. The results of phase 3 when V_{up} applied was 3.83 m/h reveal that higher values of TSS and VSS were obtained in the effluent. Although the values of suspended solids can be considered still low, it seems that values of V_{up} up to 2.5 m/h are indicated for good solid retention in the case of flocculent sludge that developed in the EGSB reactor. Nevertheless, the values of suspended solids in all three phases can be considered very good for such reactor types and the operational conditions imposed. The improved solids retention, compared with those obtained in previous studies (Vieira *et al.*, 2000), can largely be credited to the improvement in the settler device. The good settling characteristics of the sludge can also have contributed to the retention of the viable biomass in the EGSB. As reported previously (Florencio *et al.*, 2001; Arantes, 2001), the high content of inert fraction (60%) in the influent suspended solids, as well in the seed sludge, possibly contributed to form a relatively dense flocculent sludge inside the EGSB reactor. The retention of the biomass contributed significantly to the stable reactor operation observed during the whole experimental period.

Conclusions

The performance of the reactor EGSB used as post-treatment unit for anaerobic effluent was highly significant, since high COD removal efficiency, suspended solids retention and reactor operation stability were achieved. Values of total and filtered COD in the effluent of less than 87 mg/L and 55 mg/L, respectively, were obtained for a HRT of only 4 hours. Average values of TSS and VSS in the effluent were below 32 mg/L and 24 mg/L, respectively.

There was no significant difference in COD removal efficiency when the reactor was operated with liquid upflow velocities between 1.23 m/h and 3.83 m/h. This can be attributed to the low applied sludge loading rate of about 0.1 g COD/g VSS.d or 1.4 g COD/L.d. Additionally, the favorable hydrodynamic conditions, the flocculent sludge characteristics such as the high specific methanogenic activity and good settling proprieties, combined with the use of adequate settler, were the decisive factors to indicate the potential of the EGSB reactor type for post-treatment of anaerobic effluents of very low concentration from domestic sewage.

The reactor can particularly be useful in the case where there is shortage of land for polishing ponds, for instance, such is the case in dense urban centres. Nevertheless, further development in the EGSB reactor system can still be achieved. Up-scaling of the reactor system and longer term monitoring should be followed.

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