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Performance of Anaerobic Sequencing Batch Biofilm Reactor Submitted to Different Influent Volume Feeds and Cycle Time Periods Maintaining Organic Loading

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Abstract

The stability and efficiency of an anaerobic reactor containing biomass immobilized on polyurethane foam were assessed. The reactor with mechanical stirring of 500 rpm and maintained at 30 ± 1°C treated synthetic wastewater with a concentration of approx 500 mg of chemical oxygen demand/L and was fed with different influent volumes and cycle times maintaining organic load. Operation was in batch mode with renewal of only part of the volume of wastewater to be treated; that is reactor discharge was not complete, but partial. The main operational characteristic investigated was the ratio of the volume of wastewater fed per cycle (V_A) to the volume of wastewater in the reactor (V_u) maintaining the same volumetric organic load. This way, operating flexibility could be verified in relation to the volume of treated wastewater at each cycle and the cycle time for the same organic load. The results indicated that the reactor was able to operate with different V_A/V_u ratios with no significant loss in performance, thus allowing increased

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operational flexibility. For conditions in which V_A was ≥50% of V_u, removal efficiencies of filtered and nonfiltered organic matter were about 84 and 79%, respectively, whereas at conditions of higher initial influent dilution, these efficiencies were slightly lower, about 80 and 74%, respectively. At higher initial influent dilutions, it became difficult to maintain a constant reactor medium volume, owing to a high formation rate of viscous polymer-like material, likely of microbiologic origin.

Index Entries: Anaerobic sequencing batch reactor; anaerobic treatment; immobilized biomass; feed volume; cycle time; organic load.

Introduction

The development of anaerobic processes for wastewater treatment has shown great progress in recent years owing to novel bioreactor designs with the aim of improving efficiency and stability and minimizing implementation and operating costs. Among these novel anaerobic reactor designs are the anaerobic sequencing batch reactors (ASBRs) *(1–5)*, which show great potential for use on an industrial scale.

Several investigations have been performed on applied volumetric organic load (VOL), specific organic load, stirring intensity and frequency, temperature, and different ASBR designs. Yet, investigations focusing on the influence of feed strategy and especially on the initial dilution of the influent are still rare in the literature.

Modifying ASBR operational conditions such as a longer feed time or an incomplete discharge of reactor medium at each new cycle, resulting in initial influent dilution, might increase process performance, avoiding accumulation of intermediate volatile acids and reducing the amount of alkalinity necessary to neutralize the acids formed and maintain the pH at a convenient and favorable value to the process *(6)*. Moreover, this initial influent dilution might minimize the effect of initial shock loads on the system when high-strength effluents are involved, as well as the effect of the presence of toxic substances in the wastewater. In this case, if the toxic compound is biodegradable, degradation can occur before attainment of inhibitory concentrations, conferring higher operating stability and flexibility *(6)*.

Massé et al. *(7)* showed that fill time and reaction time did not significantly affect the performance of ASBRs (40-L useful volume and operated at 20°C) under intermittent agitation in treating piggery wastewater, which attained chemical oxygen demand (COD) removal efficiencies above 84%. Bagley and Brodkorb *(6)* investigated glucose degradation in a laboratory-scale ASBR applying a VOL of 1 and 2 g of COD/(L·d) and verified for short feed times accumulation of volatile acids, especially propionic acid. For a VOL of 1 g of COD/(L·d) but with a longer feed time, they verified that although organic matter concentration in the reactor was lower during the cycle, resulting in lower reaction rates, volatile acids concentration in the reactor and in the effluent was lower and stability was attained more quickly.

Chang et al. *(8)* assessed the performance of ASBRs in treating sludge from a wastewater treatment plant. Reactors were operated with renewal of only part of the medium volume. One of the operating conditions involved a 3-h cycle time with a renewal of 30% medium volume and another one a 4-h cycle time with a renewal of 40% medium volume, to maintain constant the relation among the volume fed per cycle, the volume inside the reactor, and 10-d cycle time at both conditions. The investigators concluded that the relation between renewed volume and medium volume did not affect reactor stability and performance, and COD removal efficiencies above 90% were attained. The concentration of influent organic matter varied from 11.1 to 21.6 g of COD/L, resulting in a VOL varying between 1.05 and 2.20 g of COD/(L·d).

Shizas and Bagley *(9)* investigated the effect of influent concentration, cycle time, and relation of feed time/cycle time on the performance of an ASBR treating glucose-based wastewater. They observed that longer feed times resulted in a decrease in the accumulation of volatile acids. In investigating the effect of feed strategy on the performance of an ASBR with liquid-phase circulation containing immobilized biomass on polyurethane foam cubes for treating synthetic wastewater (500 mg of COD/L), Orra et al. *(10)* observed a slight drop in the removal efficiency of filtered organic matter (as COD), from 85 to 81%, when feed time was increased from 6 to 360 min.

Borges et al. *(11)* used a mechanically stirred ASBR containing immobilized biomass on polyurethane foam cubes to study the effect of feed time on system stability and efficiency. They observed that for ratios of feed time to cycle time <0.5 the system attained removal efficiencies of filtered and nonfiltered organic matter of 75 and 70%, respectively. However, for the conditions in which these ratios were >0.5, efficiency dropped and extracellular polymer was formed.

In this context, the aim of the current investigation was to assess the effect of initial influent dilution—obtained by altering influent feed volume per cycle and cycle time and maintaining applied organic load constant—on the stability and efficiency of a mechanically stirred ASBR containing immobilized biomass on polyurethane foam for treating synthetic wastewater.

Materials and Methods

The reactor shown in Fig. 1 consisted of an acrylic cylindrical column with a diameter and height both of 20 cm and a total nominal capacity of 6 L. Agitation of 500 rpm was provided by a six-vertical-blade disk turbine impeller with an external and an internal diameter of 6 and 4.5 cm, respectively. Feeding and discharge were performed using diaphragm pumps equipped with automatic timers. The chamber in which the reactor remained was kept at 30 ± 1°C by a heating system composed of resistances and fans, as well as a temperature sensor and controller.

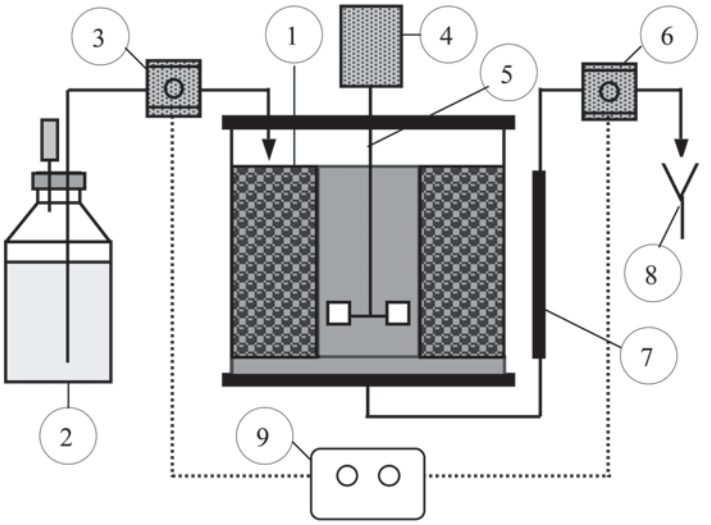

Fig. 1. Scheme of ASBR containing immobilized biomass: 1, reaction tank; 2, substrate; 3, feed pump; 4, mechanical stirrer; 5, turbine impeller with six flat blades; 6, discharge pump; 7, side reservoir; 8, treated effluent; 9, automation system; thick black bars, hydraulic connections; dashed lines, electrical connections.

As immobilizing support, 1-cm polyurethane foam cubes were used. The inoculum used in all experiments came from an upflow anaerobic sludge blanket reactor treating wastewater from a poultry slaughterhouse.

The reactor was fed with synthetic wastewater of approx 500 mg of COD/L composed of sucrose (35 mg/L); starch (114 mg/L); cellulose (34 mg/L); meat extract (208 mg/L); soybean oil (51 mg/L); NaCl (250 mg/L); $MgCl_2 \cdot 6H_2O$ (7 mg/L); $CaCl_2 \cdot 2H_2O$ (4.5 mg/L); $NaHCO_3$ (200 mg/L); and commercial detergent, in order to emulsify the soybean oil (3 drops/L). The substrate was sterilized (121°C, 15 min), in order to maintain its characteristics during the experimental time.

The batch cycle time varied proportionally to the ratio between the volume of wastewater fed per cycle (V_A, which is exactly equal to the volume discharged, i.e., the volume treated per cycle) and the volume of wastewater in the reactor (V_u, which was kept at a constant value of 2.5 L in all assays), so as to maintain constant a VOL of approx 1.5 g of COD/(L·d). Hence, the assay considered as standard condition (1) was performed with wastewater feed of 2.5 L in an 8-h cycle (3 cycles/d). This volume was the total volume contained in the reactor; that is, at this condition no residual volume was present. The remaining conditions studied were as follows: (2) V_A = 1.87 L with a residual volume of 0.63 L and 6-h cycle (4 cycles/d); (3) V_A = 1.25 L with a residual volume of 1.25 L and 4-h cycle (6 cycles/d); (4) V_A = 0.63 L with a residual volume of 1.87 L and 2-h cycle (12 cycles/d); and (5) V_A = 0.31 L with a residual volume of 2.19 L and 1-h cycle (24 cycles/d). This way, the system from batch operation tended to approach continuous

operation, since the organic volumetric load added to the reactor remained constant, reducing cycle time and effluent volume treated per cycle.

Feed (at the beginning of the cycle) and discharge time (at the end of the cycle) varied from 1 to 10 min, according to the renewed volume. After emptying the reactor, a 1-min time span was established to ensure synchronism of the timer-controlled feed and discharge pumps, to then initiate the next cycle.

The operating variables monitored according to *Standard Methods for Examination of Water and Wastewater (12)* were as follows: substrate concentration (measured as COD) for nonfiltered (C_{ST}) and filtered samples (C_{SF}), total solids (TS), total volatile solids (TVS), total suspended solids (TSS), volatile suspended solids (VSS), total volatile acids (TVA), and bicarbonate alkalinity (BA). The composition of the biogas generated by anaerobic degradation was analyzed by gas chromatography using a Hewlett Packard® 6890 gas chromatograph equipped with a thermal conductivity detector. The sample volume was 1 mL; the drag gas was hydrogen at a flow rate of 50.0 mL/h; and the column, injector, and detector temperatures were 35, 60, and 160°C, respectively.

After attaining operating stability, profiles were taken for the following variables: filtered organic matter concentration (C_{SF}), biogas concentration (CH_4 and CO_2), BA and TVA. These profiles allowed better understanding of the degradation routes along a cycle. All profiles were replicated, with samples taken on two different days.

For each operating condition, a first-order kinetic model was fitted to the experimental data from C_{SF} profiles taking into account residual filtered organic matter concentration (C_{SR}); the latter was determined as the value of organic matter concentration in the reactor at which the reaction rate equals zero. The model of the process is given by Eq. 1, in which C_{SF} is the filtered organic matter concentration in the reactor, C_{SIO} is the filtered organic matter concentration in the reactor at the beginning of the cycle, k is the first-order apparent kinetic constant, t is the cycle time, and C_{SR} is the residual filtered organic matter concentration *(13)*. This modified first-order model was fitted to the experimental organic matter concentration profile values by the Levenberg-Maquardt method (Microcal Origin 6.1©). It should be mentioned that the kinetic model proposed was formulated assuming homogeneous reaction kinetics; that is, the kinetic parameter k is actually an apparent constant because it includes in its synthesis the internal and external mass transfer resistance to the granules as well as the biochemical reaction phenomenon.

$$C_{SF} = (C_{SIO} - C_{SR}) \cdot e^{-k \cdot t} + C_{SR} \quad (1)$$

For all operating conditions studied, organic loading rate (OLR) and VOL were calculated for filtered and nonfiltered effluent samples as well as for nonfiltered influent samples, defined as the amount of organic matter removed by and fed to the reactor per time unit and per reactor medium volume, respectively. For batch reactors with renewal of only part of the

volume of treated wastewater per cycle, OLR for effluent filtered and nonfiltered samples was calculated using Eqs. 2 and 3, respectively, in which C_{SI} is the organic matter concentration in the influent, C_{SF} is the filtered organic matter concentration in the effluent, C_{ST} is the nonfiltered organic matter concentration in the effluent, V_A is the volume of wastewater fed per cycle, V_u is the volume of wastewater in the reactor, and t_{tra} is the time necessary to attain approximately stable organic matter concentration values inside the reactor during the cycle, i.e., the time to attain the horizontal line in the organic matter concentration profile curves. VOL for influent nonfiltered samples was calculated using Eq. 4, in which t_C is the cycle time.

$$\mathrm{OLR}_{SF} = \frac{(C_{SI} - C_{SF}) \cdot V_A}{V_u \cdot t_{tra}} \tag{2}$$

$$\mathrm{OLR}_{ST} = \frac{(C_{SI} - C_{ST}) \cdot V_A}{V_u \cdot t_{tra}} \tag{3}$$

$$\mathrm{VOL} = \frac{C_{SI} \cdot V_A}{V_u \cdot t_C} \tag{4}$$

At the end of each operating condition, the concentration of adhered biomass to the foam was measured as TSS after detachment from the support material. These samples were also submitted to microbiologic analysis employing common optical and optical fluorescence phase contrast microscopy utilizing a BH2 Olympus® microscope with a digital Optronics system and image acquisition by Image Pro-Plus version 4.5.0.

Results and Discussion

Table 1 shows the average values of organic matter concentration in the effluent for filtered (C_{SF}) and nonfiltered samples (C_{ST}), as well as average concentrations of TVA, BA, and VSS in the effluent obtained for each operating condition. Average values of molar percentage methane (% CH_4) and carbon dioxide (% CO_2) in the reactor head space at the end of each cycle, for all conditions studied, are also provided in Table 1. Figure 2 shows the values of organic matter concentration in the effluent for filtered and nonfiltered samples obtained during the entire reaction operating period.

Analysis of Table 1 shows that there was no solids loss (VSS) at any of the imposed conditions. Moreover, analysis of Fig. 2 shows that for the first three operating conditions, in which $V_A / V_u = 1$ (assay I), 0.75 (assay II), and 0.50 (assay III), the average removal efficiencies of organic matter remained about 84% for filtered samples and 79% for nonfiltered samples. For the remaining conditions, in which $V_A / V_u = 0.25$ (assay IV) and 0.125 (assay V), the highest initial influent dilution caused a slight drop in removal efficien-

Table 1
Monitored Variables of Reactor Operated at Different V_A/V_u Ratios[a]

V_A/V_u [b]	C_{SF} (mg of COD/L)[c]	C_{ST} (mg of COD/L)[c]	TVA (mg of HAc/L)[d]	BA (mg of $CaCO_3$/L)[d]	CH_4 (%)[e]	CO_2 (%)[e]	VSS (mg/L)[f]
1	79 ± 9	109 ± 22	17 ± 3	216 ± 14	—	—	25 ± 16
0.75	89 ± 12	115 ± 15	22 ± 5	200 ± 7	64 ± 4	36 ± 4	35 ± 15
0.50	84 ± 10	105 ± 17	18 ± 2	206 ± 16	56 ± 3	44 ± 3	26 ± 11
0.25	106 ± 9	139 ± 14	30 ± 9	219 ± 12	47 ± 3	53 ± 3	31 ± 18
0.125	105 ± 10	134 ± 19	23 ± 7	191 ± 26	24 ± 6	76 ± 6	34 ± 25

[a]Average influent variables for all conditions (75 samples) were as follows: C_{SI} = 525 ± 49 mg of COD/L; TVA_I = 33 ± 6 mg of HAc/L; BA_I = 122 ± 9 mg of $CaCO_3$/L; VSS_I = 42 ± 31 mg/L. Influent volume values for each condition (at least 15 samples) were as follows: (1) V_A = 2.42 ± 0.17 L with no residual volume; (2) V_A = 1.85 ± 0.15 L with a residual volume of 0.65 ± 0.09 L; (3) V_A = 1.28 ± 0.16 L with a residual volume of 1.25 ± 0.15 L; (4) V_A = 0.62 ± 0.08 L with a residual volume of 1.84 ± 0.14 L; (5) V_A = 0.34 ± 0.08 L with a residual volume of 2.15 ± 0.15 L. Biomass in the reactor (average values for all conditions—five samples) was as follows: S_{TS} = 1202 ± 74 mg/g of foam; S_{TVS} = 1074 ± 62 mg/g of foam; S_{TS} = 18 ± 2 g/L of wastewater; S_{TVS} = 16 ± 2 g/L of wastewater; S_{TVS}/S_{TS} = 90 ± 3%.

[b]Period of the condition: 65, 36, 35, 33, and 31 d, respectively.

[c]Number of samples: 26, 13, 18, 14, and 19 d, respectively.

[d]Number of samples: 13, 10, 13, 9, and 11, respectively.

[e]Number of samples: —, 2, 2, 2, and 2, respectively.

[f]Number of samples: 12, 6, 10, 7, and 9, respectively.

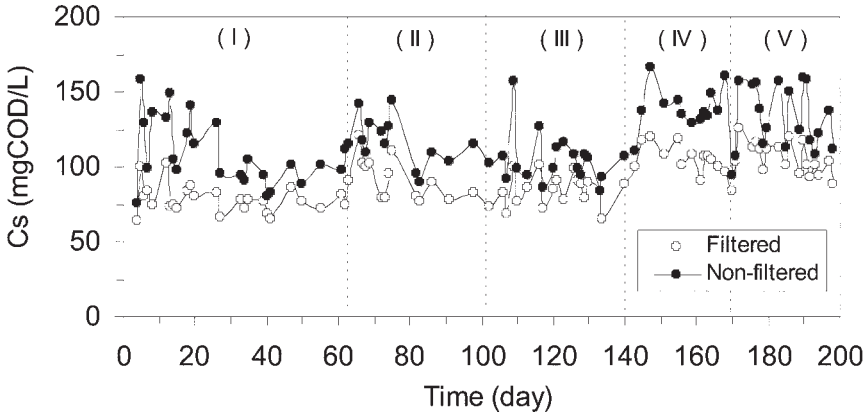

Fig. 2. Organic matter concentration in effluent during reactor operation: (I), V_A/V_u = 1; (II) V_A/V_u = 0.75; (III) V_A/V_u = 0.50; (IV) V_A/V_u = 0.25; (V) V_A/V_u = 0.125.

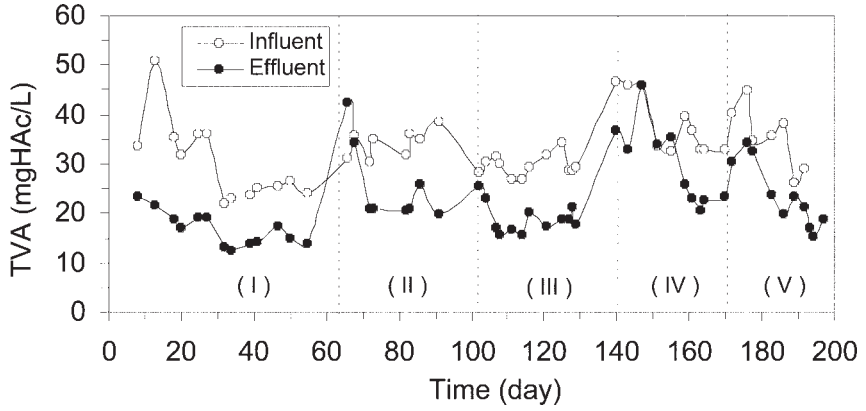

Fig. 3. Concentration of TVA during reactor operation: (I) V_A/V_u = 1; (II) V_A/V_u = 0.75; (III) V_A/V_u = 0.50; (IV) V_A/V_u = 0.25; (V) V_A/V_u = 0.125.

cies of filtered and nonfiltered organic matter, which were 80 and 74%, respectively.

Figure 3 shows the values of TVA obtained during the entire reaction operating period. From Fig. 3 and Table 1 it can be seen that the system is effective in producing BA and in consuming TVA at all proposed conditions, maintaining a pH of the medium near neutrality, favorable to the development of methanogenic microorganisms.

The last two operating conditions with low V_A/V_u ratios showed high formation of viscous polymer-like material—likely of microbiologic origin—in the polyurethane foam containing immobilized biomass. This required cleaning up the system every 7 d to avoid overflow of the medium because of lack of space as the formed material took up space in the reactor, making it difficult to maintain the reactor medium volume at 2.5 L. There

seems to be a relation between the formation of this material and an increase in substrate shortage, which occurs with decreasing V_A/V_u ratios.

It is worth mentioning that the relation between V_A/V_u and organic matter shortage exists as the process becomes a batch one; that is, from a process engineering viewpoint the reaction time for organic matter bioconversion is defined by the batch time, independent of organic load. This way, with decreasing V_A/Vu ratios, the amount of organic matter fed per cycle also decreases, leading to a shortage of available organic matter. However, since the time available for reaction also decreases, the organic load remains constant. Moreover, influent wastewater gets diluted by the residual volume, resulting in increasingly less pronounced variations in the profiles.

Table 1 also provides the concentrations of TS (S_{TS}) and TVS (S_{TVS}) relative to the immobilized biomass, for all the operating conditions studied, expressed in solids mass per foam mass and solids mass per reactor medium volume. S_{TVS} values, representative of the biomass inside the reactor, remained between 14.2 and 18.8 g/L, and the S_{TVS}/S_{TS} ratios remained between 87 and 94%, showing that the microbial community was maintained inside the reactor during the investigated operating conditions. Microbiologic analyses of the polyurethane foam containing anaerobic immobilized biomass showed the existence of bacilli and vibriones inside the foam, as well as the presence of *Methanosaeta*-like and *Methanosarcina*-like morphologies, hydrogenotrophic bacilli, nonfluorescent cocobacilli, and vibria. Equilibrium in the distribution of *Methanosaeta* sp. and *Methanosarcina* sp. genus was also observed.

Figures 4–8 present time profiles of the main monitored variables. Analysis of the time variations of organic matter and TVAs during the cycle demonstrates the tendency of these variables to stabilize as a result of a decrease in feed volume and maintenance of applied organic load by the proportional decrease in cycle time. Furthermore, the biogas time profiles show that methane and CO_2 concentrations were lower at low V_A/V_u ratios. At the second operating condition ($V_A/V_u = 0.75$), methane concentration in the reactor head space reached levels as high as 6.4 mmol/L at the end of the cycle, whereas at the last operating condition ($V_A/V_u = 0.125$), methane concentration at the end of the cycle did not exceed 0.6 mmol/L. These results might be related to very little alternation between substrate abundance and shortage imposed at low V_A/V_u ratios, contributing to no volatile acids accumulation during the cycle and controlling, therefore, the supply of substrate to the methanogenic microorganisms, resulting in less methane generation.

Based on the methane profile behavior, the decrease in organic matter concentration is a result of anaerobic biodegradation, rather than physical chemical phenomena, since the reduced values are owing to the type of bioreactor configuration with polyurethane foam as inert support. Visual inspection through the transparent reactor walls showed biogas retention in the foam interstices during the assays. Furthermore, measuring biogas concentration and production became difficult because the process is dis-

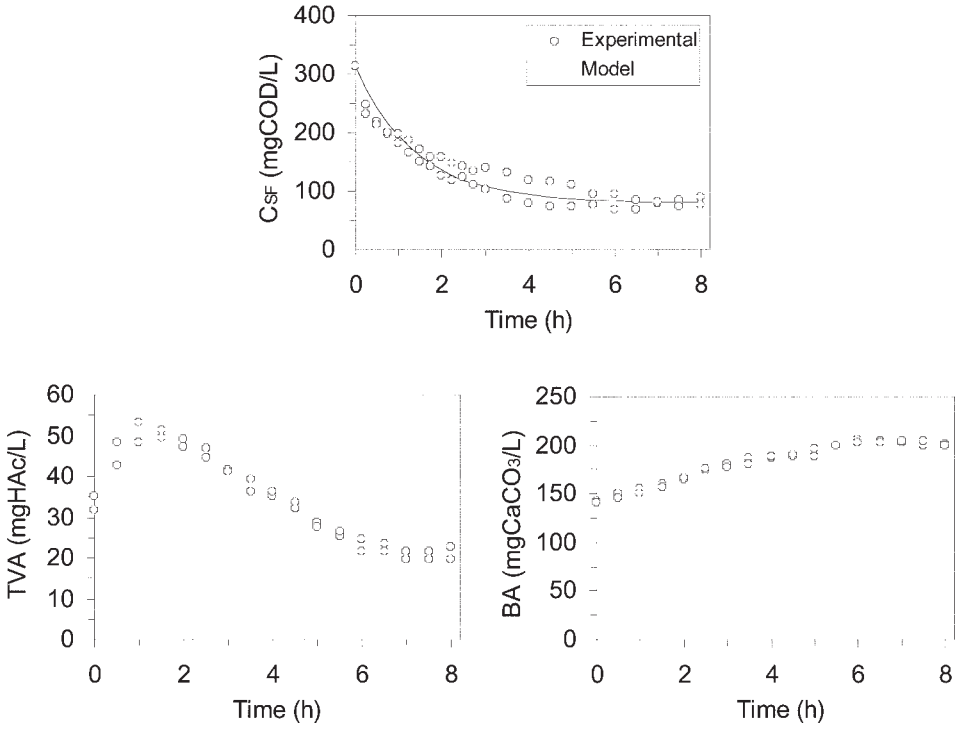

Fig. 4. Time profiles of monitored variables for condition at which $V_A/V_u = 1$.

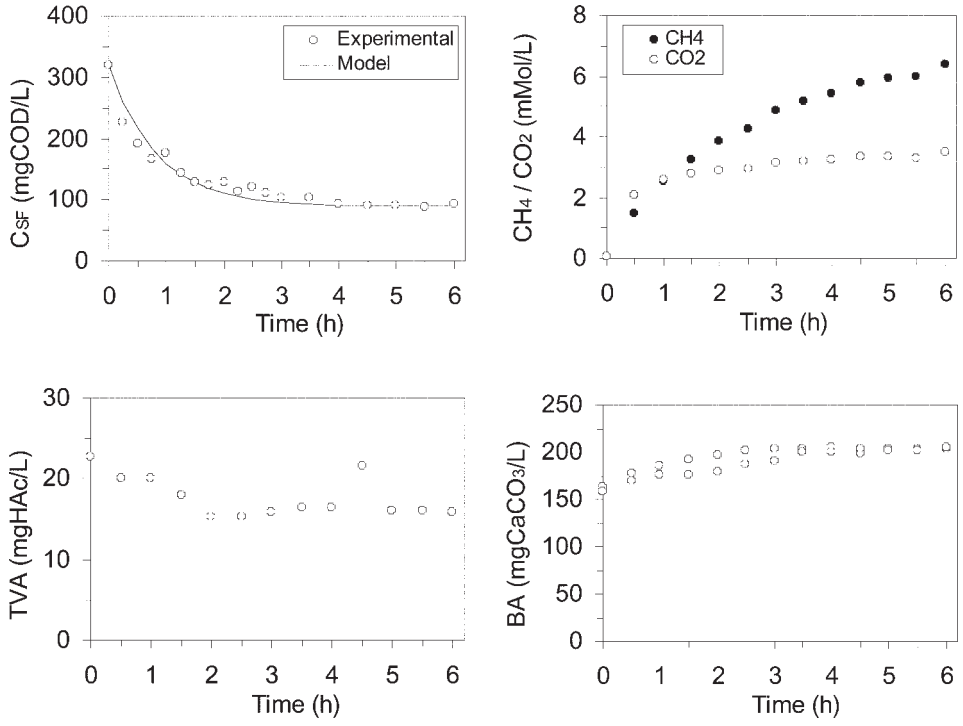

Fig. 5. Time profiles of monitored variables for condition at which $V_A/V_u = 0.75$.

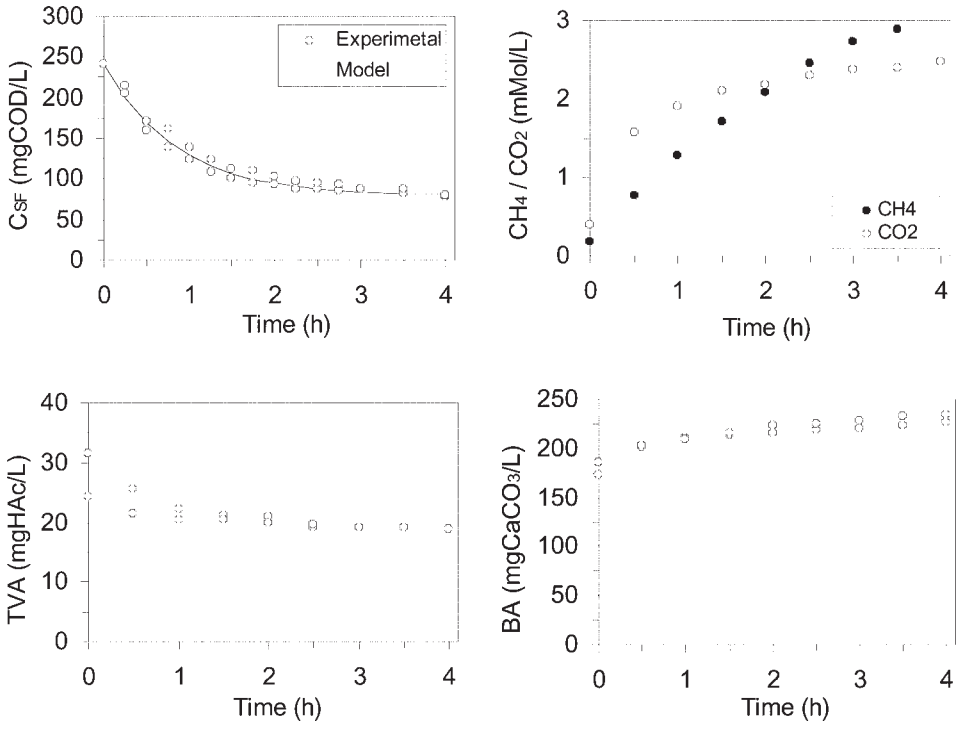

Fig. 6. Time profiles of monitored variables for condition at which $V_A/V_u = 0.50$.

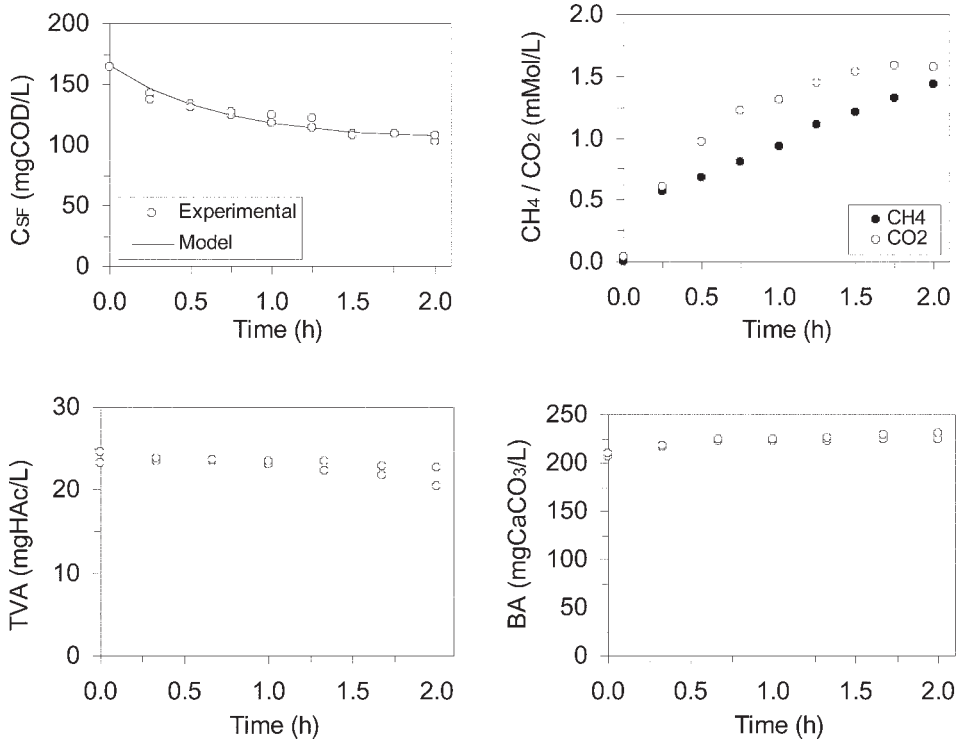

Fig. 7. Time profiles of monitored variables for condition at which $V_A/V_u = 0.25$.

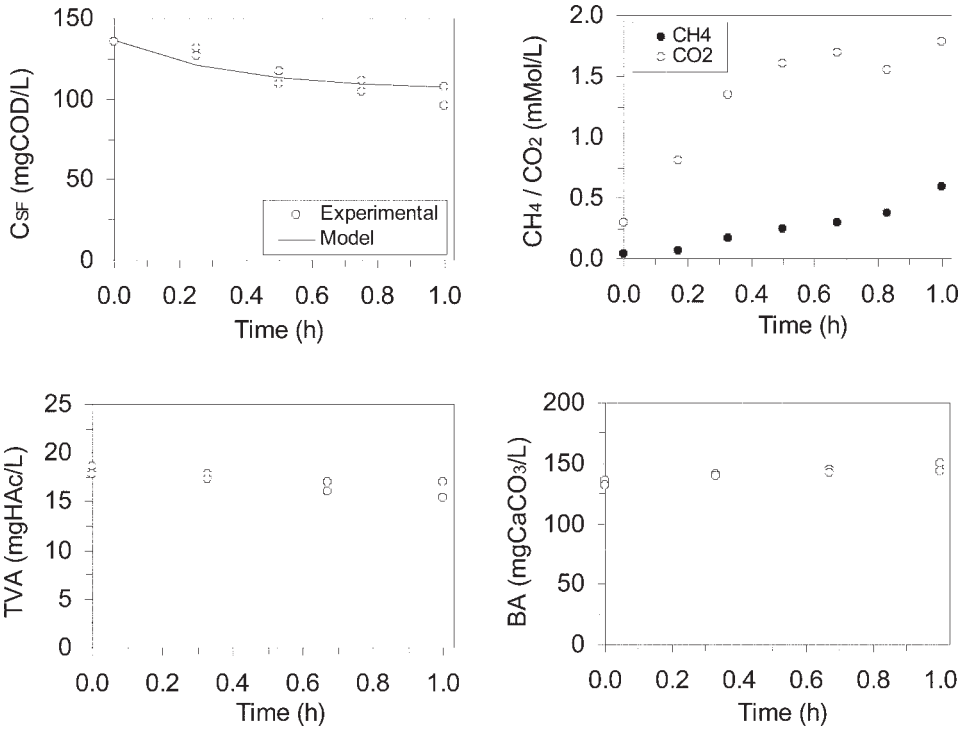

Fig. 8. Time profiles of monitored variables for condition at which $V_A/V_u = 0.125$.

continuous; that is, the reactor is charged and discharged every cycle, and there is the existence of the mechanical stirrer shaft that passes through the reactor top. The high solubility of the synthetic wastewater should also be taken into account; organic matter concentrations for nonfiltered and filtered samples amounted to 525 ± 49 (75 samples) and 512 ± 30 mg of COD/L (15 samples), respectively. Moreover, the ASBR treating the same wastewater and equipped with a sealing system between the cover and stirrer shaft but using granular biomass (i.e., no gas retention problems in the foam) showed higher methane production, even though batch operation also hampered biogas measurements *(14)*.

Volatile acids profiles showed very little variation between maximum and minimum values, because the wastewater treated was of low strength. Furthermore, when the V_A/V_u ratio decreased because of a reduction in the feed volume, this difference decreased even further, as the amount of organic matter feed diminished.

Table 2 shows the values of the first-order apparent kinetic constant (k) obtained by fitting the kinetic model to the time profile of filtered organic matter concentration for all the investigated operating conditions. Values of residual filtered organic matter concentration, initial removal rate of organic matter, and correlation coefficient squared are also provided. It can be seen that despite the increase in k (from 0.71 to 2.74/h) with decreasing

Table 2
Values Obtained by Fitting Kinetic Model to Experimental Data

V_A/V_u	C_{SIO} (mg of COD/L)	k (h^{-1})	C_{SR} (mg of COD/L)	V_I (mg of COD/[L·h])	R^2
1	312	0.71 ± 0.03	80	164.7	0.923
0.75	320	1.22 ± 0.08	90	280.6	0.945
0.50	241	1.20 ± 0.04	80	193.2	0.972
0.25	165	1.48 ± 0.08	104	90.28	0.954
0.125	136	2.74 ± 0.51	105	84.94	0.828

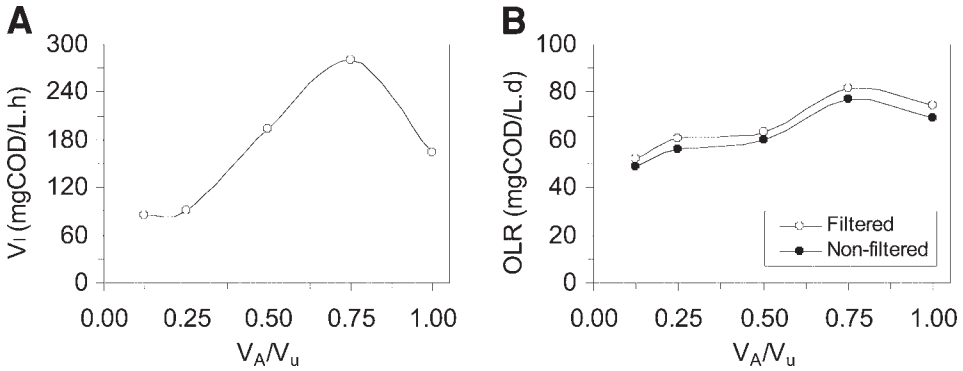

Fig. 9. **(A)** Initial removal rate of filtered organic matter and **(B)** OLR as function of V_A/V_u.

Table 3
Values of OLR by Reactor at Different V_A/V_u Ratios

		OLR (mg of COD/[L·h])	
V_A/V_u	t_{tra} (h)	Filtered samples	Nonfiltered samples
1	6.00	74.3	69.3
0.75	4.00	81.5	76.7
0.50	3.50	63.0	60.0
0.25	1.75	60.3	55.6
0.125	1.00	52.1	48.5

V_A/V_u ratio, the initial reaction rates show a maximum for the ratio of 0.75 (*see* Fig. 9A), indicating that this ratio might be close to the "best ratio" for this system. It is, hence, believed that this behavior might be related to the way by which the substrate becomes available to the microorganisms as a function of the relation between the volume of feed wastewater and the residual volume maintained in the reactor from one cycle to the other, which, in some way, collaborates to a faster metabolism of organic matter.

Table 3 presents the time required to reach the plateau in the organic matter concentration (t_{tra}) profile curves. OLR values for filtered and nonfiltered effluent samples calculated for all investigated operating con-

ditions are also provided. Figure 9B depicts the variation in OLR as a function of V_A/V_u ratio. Analysis of Table 3 and Fig. 9B demonstrates that, in general, the organic load removed by the reactor dropped for filtered and nonfiltered samples in the effluent with decreasing V_A/V_u except for the second operating condition (V_A/V_u = 0.75), where the highest removed organic load occurred for filtered and nonfiltered samples in the effluent, which was 81.5 and 76.7 mg of COD/(L·d), respectively. This result indicates that the best way to operate the reactor is that at which 75% of the medium volume is renewed at each cycle.

Conclusion

By maintaining VOL at different conditions and proportionally decreasing the amount of organic matter added, system stability was maintained, qualifying reactor flexibility as far as this operating strategy is concerned.

Conditions with $V_A/V_u \geq 0.5$ presented filtered and nonfiltered organic matter removal efficiencies of about 84 and 79%, respectively, whereas at the remaining conditions, in which $V_A/V_u \leq 0.25$, these efficiencies were slightly lower, at about 80 and 74%, respectively.

The highest OLR value for filtered and nonfiltered effluent samples was obtained when the reactor was operating with a renewal of 75% of the medium volume at each cycle, the best operating mode of all the assessed operating conditions. This conclusion is ratified by analysis of the initial removal rate of organic matter; however, lower V_A/V_u ratios resulted in higher values of the first-order apparent kinetic constant.

Maintaining constant reactor volume medium at lower V_A/V_u ratios became difficult owing to the high formation rate of viscous polymer-like material, likely of microbiologic origin.

Acknowledgments

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Nomenclature

BA = BA in effluent (mg of $CaCO_3$/L)
BA_I = BA in influent (mg of $CaCO_3$/L)
C_S = substrate concentration in reactor (mg of COD/L)
C_{SF} = filtered substrate concentration in effluent (mg of COD/L)
C_{SI} = nonfiltered substrate concentration in influent (mg of COD/L)
C_{SIO} = filtered organic matter concentration in reactor at beginning of cycle (mg of COD/L)
C_{SR} = filtered residual organic matter concentration (mg of COD/L)
k = apparent first-order kinetic parameter (h^{-1})

OLR_{SF} = removed organic load for filtered effluent samples (mg of COD/[L·h])

OLR_{ST} = removed organic load for nonfiltered effluent samples (mg of COD/[L·h])

R^2 = correlation coefficient squared

S_{TS} = TS concentration relative to immobilized biomass (mg of solids/g of foam or g of solids/L of reaction medium)

S_{TVS} = TVS concentration relative to immobilized biomass (mg of solids/g of foam or g of solids/L of reaction medium)

S_{TVS}/S_{TS} = ratio between TVS and TS relative to immobilized biomass

t_C = cycle time (h or d)

TS = TS concentration (mg/L)

TSS = TSS concentration (mg/L)

t_{tra} = time necessary to attain approximately stable values of organic matter concentration inside reactor during a cycle (h)

TVA = TVA concentration in effluent (mg of HAc/L)

TVA_I = TVA concentration in influent (mg of HAc/L)

TVS = TVS concentration (mg/L)

V_A = volume of wastewater fed per cycle (L)

V_A/V_u = ratio of volume of wastewater fed per cycle to volume of wastewater in reactor

V_I = initial removal rate of filtered organic matter (mg of COD/[L·h])

VOL = volumetric organic load (mg of COD/[L·d])

VSS = VSS concentration (mg/L)

VSS_I = VSS concentration in influent (mg/L)

V_u = volume of wastewater in reactor (L)

ε = removal efficiency of organic matter in system (%)

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