0273-2289/1559-0291 (Online)/06/133/0171/$30.00

Analysis of Performance of an Anaerobic Sequencing Batch Reactor Submitted to Increasing Organic Load With Different Influent Concentrations and Cycle Lengths

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Received March 28, 2005; Revised September 12, 2005; Accepted October 5, 2005

Abstract

The performance of an anaerobic sequencing batch reactor (ASBR) was assessed when submitted to increasing organic load with different influent concentrations and cycle lengths. The 5-L mechanically stirred (75 rpm) ASBR contained 2 L of granular biomass and treated 2 L of synthetic wastewater per cycle. Volumetric organic loads (VOLs) from 0.66 to 2.88 g of chemical oxygen demand (COD)/(L·d) were applied by using influent concentrations from 550 to 3600 mg of COD/L in 8- and 12-h cycles. Reactor stability was maintained for VOLs from 0.66 to 2.36 g of COD/(L·d), with organic matter removal efficiencies for filtered samples (ε_F) between 84 and 88%. For VOLs from 0.78 to 2.36 g of COD/(L·d) at an influent concentration of 2000 mg of COD/L, when cycle length was reduced from 12 to 8 h, ε_F did not vary, yet showed a very distinct behavior from the other conditions. In addition, two operation strategies were studied for VOLs with approximately similar values of 2.36 and 2.08 g of COD/(L·d). One involved operation with an influent concentration of 2000 mg of COD/L and an 8-h cycle, whereas the other

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involved an influent concentration of 2600 mg of COD/L and a 12-h cycle. Only the former resulted in system stability and efficiency. These results indicate that besides organic load, influent concentration and cycle length play a significant role in ASBR systems.

Index Entries: Anaerobic sequencing batch reactor; organic load; influent concentration; cycle length.

Introduction

Anaerobic sequencing batch reactors (ASBRs) have recently drawn much attention for the treatment of wastewaters in general. According to Dague et al. *(1)*, the basic characteristic of intermittent-flow ASBRs is the charging with wastewater at the beginning and discharging at the end of the treatment, with this operation repeated with each new batch. The reactor content is mixed, allowing good contact between wastewater and biomass. Treatment takes place in a single tank in an operation sequence comprising basically the following phases: (1) filling the reactor with wastewater; (2) treating by means of biotransformations of the wastewater constituents by microbial activity; (3) allowing the biologic sludge to settle after terminating the reaction; and (4) emptying the reactor by withdrawing the treated, clarified liquid.

Although still in a developmental stage, the use of ASBRs is promising, because these reactors have been shown to be adequate for low-strength effluents, such as domestic wastewaters, as well as for operation at temperatures much lower than usual. Sung and Dague *(2)* reported that the effect of organic load on the formation of granules was improved settling characteristic. Another important issue is wastewater type; some wastewaters may cause operational problems owing to high acidification reaction rates related to biodegradation. According to Bagley and Brodkorb *(3)*, feeding ASBRs with readily acidifiable wastewater may lead to the accumulation of volatile acids, because the production rate of these acids by acidogenic organisms is higher than the consumption rate by acetogenic and methanogenic microorganisms.

For a better understanding and dissemination of ASBR technology, comparison with the currently prevailing continuous reactors has become a must. To this end, utilization of well-established wastewater parameters, including volumetric organic load (VOL) and specific organic load (SOL), is needed. It should be pointed out that these parameters complement information about batch reactor design. While the hydraulic residence time gives an idea of the time required for processing a certain volume contained in a reactor, VOL and SOL allow identification of the organic load applied per time and volume units, and per biomass unit, respectively *(4,5)*.

Currently, ASBRs have been investigated for treating high-strength wastewaters, which include effluents from dairy industries, wastes generated from intensive swine breeding, and landfill leachate, as given in Table 1.

Table 1
Treatment of Wastewaters Using ASBRs[a]

Type of influent	Volume/type of bioreactor	VOL (g COD/[L·d])	Cycle length (d)	C_I (g COD/L)	T (°C)	ε (%)	Reference
SN	16 L^{G}	0.2 ± 6.45	1 ± 15	6.5 ± 14	28	53 ± 89	*6*
LDP	13 $L^{G, RB}$	4	1.08 ± 2.17	0.3 ± 6.0	35	>80	*1*
SN	12 $L^{G, RB}$	1.04 ± 6.82	6	6.3 ± 40	20	>74	*1*
P	12 $L^{G, RB}$	1.6 ± 3.5	12 ± 48	1.1 ± 3.5	35	85 ± 90	*7*
LPD	11.5 L^{G}	1.5 ± 10	24	1.04	35	70–95	*8*
LPD	12 $L^{G, IN}$	2 ± 12	12 ± 48	1.04	35	>90	*2*
SC	12 $L^{G, RB}$	19	0.5	3 ± 9.5	35	>90	*9*
LPD	6 L^{G}	0.4–1.0	12 ± 48	0.2 ± 2	15 ± 35	86 ± 99	*10*
S	1.2 $L^{G, PL}$	5 ± 6	—	1	22	60 ± 70	*11*
P	2.0 $L^{G, IN}$	0.4 ± 9.4	1.5 ± 10	3.8 ± 15.9	35	64 ± 85	*12*
V	5 $L^{G, IN}$	8.6	2.2	19.7	35	>98	*13*
S	2.5 $L^{I, M}$	1.5	0.66	0.5	30	86	*14*
G	1.2 $L^{I, R}$	0.5	0.33	0.5	30	85	*15*
S	1.2 $L^{I, R}$	0.5	0.33	0.5	30	87	*16*
S	5.4 $L^{I, M}$	1.5 ± 6	0.3 ± 0.5	0.5 ± 2.0	30	73 ± 88	*17*
			0.3	2.0		55	
S	5 $L^{G, M}$	0.77	0.63	0.5	30	87	*18*

[a]VOL, volumetric organic load; T, temperature; ε, efficiency; C_I, influent concentration; LPD, skim milk; SN, swine; G, glucose; S, synthetic; V, winery; P, landfill leachate; SC, sucrose; G, granular biomass; I, immobilized biomass; M, mechanical stirring; R, recirculation of liquid phase; PL, pulse homogenization; RB, recirculation of biogas; IN, intermittent stirring.

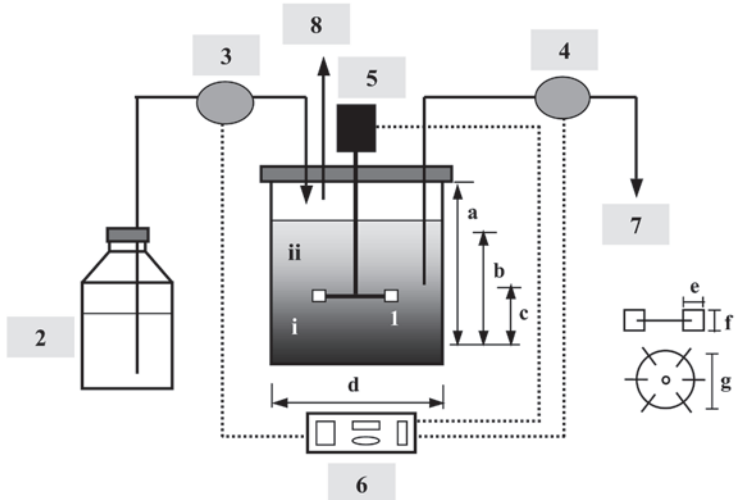

Fig. 1. Scheme of stirred ASBR containing granular biomass: 1, bioreactor with capacity of 5 L (a = 26 cm; b = 20 cm; c = 16 cm; d = 18 cm) and turbine impeller with six vertical flat blades (e = 2 cm; f = 1.5 cm; g = 6 cm) containing granular biomass (i = region of high biomass concentration; ii = region of low biomass concentration); 2, influent; 3, feed pump; 4, discharge pump; 5, stirring system; 6, automation system; 7, effluent; 8, biogas outlet.

The main objective of the present study was to assess the performance of a mechanically stirred ASBR containing granular biomass on treating synthetic wastewater when submitted to increasing organic load with different influent concentrations and cycle lengths and, hence, to verify the limiting VOL value as well as the importance of the effects of these operational conditions.

Materials and Methods

The system proposed, shown in Fig. 1, consisted of a 5-L acrylic reactor containing granular biomass. Mechanical agitation at 75 rpm was provided by a turbine impeller with a shaft diameter of 60 mm, having six 15- × 15-mm vertical flat blades (Rushton type), at a distance of 60 mm from the bottom of the reactor. The reactor was maintained at a constant temperature of 30 ± 2°C.

The inoculum used in all experiments came from a UASB reactor treating poultry slaughterhouse wastewater. Inoculum concentrations in terms of total solids (TS) and total volatile solids (TVS) were about 62 and 51 g/L, respectively.

The synthetic domestic wastewater, with a chemical oxygen demand (COD) of approx 500 mg of COD/L, consisted of carbohydrates (35 mg/L of sucrose, 114 mg/L of starch, and 34 mg/L of cellulose), proteins (208 mg/L of meat extract), and lipids (51 mg/L of soybean oil) at a proportion of 40, 50, and 10% of total COD, respectively. The synthetic wastewater also contained salts (250 mg/L of NaCl, 7 mg/L of $MgCl_2·6H_2O$, and 4.5 mg/L of $CaCl_2·2H_2O$), and an alkaline source (200 mg/L of $NaHCO_3$). Concentrations used ranged from 550 to 3600 mg of COD/L, with constituents being added proportionally. The media were sterilized (121°C, 15 min) in order to maintain their characteristics during the experimental time.

At the beginning of the assay, 2 L of inoculum and 3 L of wastewater were added to the reactor. Two liters of wastewater was treated per cycle; that is, in each cycle this volume of treated wastewater was discharged and an equal volume of untreated wastewater was fed to the reactor.

During reactor operation, samples were taken from the influent and the effluent for organic matter analyses as COD (from the effluent as filtered, C_{ES}, and nonfiltered, C_{ET}; and from the influent as nonfiltered, C_I). The following were also analyzed: total volatile acids (TVA); bicarbonate alkalinity (BA); organic nitrogen (as total Kjeldahl, TKN-N; and organic, N_{Org}-N) and inorganic nitrogen (as ammonium, NH_4^+-N; nitrate, NO_3^--N; and nitrite, NO_2^--N); TS and total suspended solids (TSS); TVS and total volatile suspended solids (VSS); pH and volume fed per cycle (V_F). Analyses were performed according to *Standard Methods for the Examination of Water and Wastewater (19)*. Moreover, biogas composition and intermediate volatile acids were analyzed using a Hewlett Packard® 6890 gas-phase chromatograph equipped with a thermal conductivity detector and a flame ionization detector, respectively.

VOLs ranging from 0.66 to 2.88 g of COD/(L·d) in 8- and 12-h batches were used to assess the effect of organic load on ASBR performance. In both cases, 10 min was used for loading and 10 min for discharge after 30 min for the sludge to settle, as well as a delay time of 1 min between operations, to ensure synchronism of the timer-controlled feed and discharge pumps.

The remaining time was reserved for the reaction step. As soon as C_{ET}, C_{EF}, TVA, and BA values showed no significant variations from one cycle to the next, duplicate time profiles of these variables were obtained during a batch. Samples for obtaining these profiles were collected at time intervals that respected the maximum sampling volume: 10% of the total reactor medium volume.

At the end of each experimental condition, the reactor was dismounted for cleaning and inspection, and a sludge sample was collected for solids quantification and microbiologic analysis. Solids quantification was performed by measuring the concentration of a 15-mL sample taken from the medium containing the granular sludge, previously homogenized with a glass rod. Microbiologic analysis of the anaerobic sludge was performed through phase contrast optical microscopy employing a BH2 Olympus® microscope. These analyses were performed at the end of the experiments and allowed observation of several groups of microorganisms characteristic of anaerobic biomass.

Substrate removal efficiencies for filtered (ε_S) and nonfiltered (ε_T) samples were calculated using Eqs. 1 and 2, respectively, in which, C_I, C_{ES}, and C_{ET} represent organic concentration in the influent, filtered effluent, and nonfiltered effluent samples, respectively:

$$\varepsilon_S = \frac{C_I - C_{ES}}{C_I} \tag{1}$$

$$\varepsilon_T = \frac{C_I - C_{ET}}{C_I} \tag{2}$$

Specific organic matter removal for nonfiltered (SOR_T) and filtered samples (SOR_F) was calculated using Eqs. 3 and 4, respectively, in which V_F is the volume fed per cycle, V is the total volume of liquid medium in the reactor, and C_X is the average biomass concentration inside the reactor:

$$SOR_T = \frac{V_F \cdot (C_I - C_{ET})}{C_X \cdot V} \tag{3}$$

$$SOR_F = \frac{V_F \cdot (C_I - C_{ES})}{C_X \cdot V} \tag{4}$$

VOL and SOL were calculated using Eqs. 5 and 6, respectively, in which t_C is the cycle length:

$$VOL = \frac{V_F \cdot C_I}{V \cdot t_C} \tag{5}$$

$$SOL = \frac{V_F \cdot C_I}{C_X \cdot V \cdot t_C} \tag{6}$$

Results and Discussion

The mechanically stirred ASBR containing granular biomass and treating synthetic wastewater was submitted to seven different experimental conditions. Tables 2–6 provide the average values of the main parameters monitored for all the implemented conditions. Each operation lasted 33 d under condition I, 25 d under condition II, 24 d under condition III, 25 d under condition IV, 22 d under condition V, 8 d under condition VI, and 14 d under condition VII. Figure 2 shows the removal efficiencies for filtered and nonfiltered samples.

At condition I, the reactor was operated with an influent concentration of 550 mg of COD/L and an 8-h cycle, attaining stability and a removal efficiency of 88% in terms of filtered samples. At condition II, influent concentration was increased to 1000 mg of COD/L and cycle length to 12 h; an increase in VOL (from 0.66 to 0.78 g of COD/[L·d]) did not reduce efficiency, which equaled 87%.

At condition III, an influent concentration of 1000 mg of COD/L was maintained and cycle length was reduced to 8 h, increasing the organic load to 1.22 g of COD/(L·d). A gradual decrease in efficiency was observed with

Table 2
Operational Values for Influent[a]

Condition	t_{Ciclo} (h)	C_I (mg COD/L)	BA (mg $CaCO_3$/L)	TVA (mg/L)
I	8.0	546 ± 73 (19)	117 ± 16 (7)	37 ± 9 (7)
II	12.0	972 ± 50 (18)	217 ± 43 (7)	52 ± 5 (7)
III	8.0	1014 ± 83 (15)	244 ± 6 (11)	48 ± 3 (11)
IV	12.0	1938 ± 128 (10)	484 ± 16 (6)	76 ± 4 (6)
V	8.0	1964 ± 117 (9)	471 ± 6 (6)	79 ± 9 (6)
VI	12.0	3599 ± 216 (4)	964 ± 11 (2)	123 ± 1 (2)
VII	12.0	2594 ± 116 (5)	732 ± 31 (4)	100 ± 16 (4)

[a]Average values for all conditions: pH = 8.6 ± 0.9. Values in parentheses refer to the number of samples analyzed in each condition.

operation time. This decrease was a result of loss of part of the biomass, which formed a floating layer, requiring removal of this layer. The reactor was then reinoculated with 600 mL of sludge to replace the lost amount. Formation of this layer continued throughout the assays. To prevent disposal of this layer together with the effluent during reactor discharge, the tube connected to the discharge pump (Fig. 1) had to be lowered. After this adjustment in the discharge system, stability could be obtained and the removal efficiency attained was 84%.

At this point it should be mentioned that a volume of 2 L (measured in a measuring cylinder) of the same sludge was always maintained in the reactor except for the supplemental addition of anaerobic sludge used as inoculum as previously mentioned. Solids analyses in the influent and effluent indicate that there was no significant loss of sludge (see Tables 5 and 6). The major part of these solids may be represented by the soluble fraction, because the wastewater practically does not contain suspended matter. In spite of this, biomass concentration in the reactor increased from 14 to 23 g of TVS/L, which might be owing to the uncertainty of the measuring method used.

At condition IV, influent concentration was increased to 2000 mg/L and cycle length to 12 h, resulting in a VOL of 1.55 g of COD/(L·d), with no detriment to system efficiency, which remained at 84%. At condition V, influent concentration was kept at 2000 mg of COD/L and cycle length reduced to 8 h, resulting in an increase in VOL to 2.36 g of COD/(L·d), with no detriment to system efficiency, which remained at 84%.

At condition VI, influent concentration was further increased to 3600 mg of COD/L and cycle length to 12 h, resulting in a VOL of 2.88 g of COD/(L·d), at which the system could not maintain stability and accumulation of TVA occurred, whose concentration in the effluent reached 171 ± 35 mg/L. To recover system efficiency, the strategy adopted at condition VII was to reduce the influent concentration down to 2600 mg of COD/L and maintain cycle length at 12 h, reducing VOL to 2.08 g of COD/(L·d). Even so, stability could not be obtained and accumulated TVA var-

Table 3
Operational Values for Effluent[a]

Condition	C_{ST} (mg COD/L)	ε_T (%)	C_{SS} (mg COD/L)	ε_S (%)	BA (mg $CaCO_3$/L)	TVA (mg/L)
I	113 ± 26 (19)	79 ± 5	66 ± 12 (19)	88 ± 2	239 ± 19 (14)	21 ± 5 (14)
II	180 ± 21 (18)	81 ± 2	130 ± 16 (18)	87 ± 2	453 ± 34 (10)	24 ± 3 (10)
III	242 ± 23 (14)	79 ± 2	180 ± 18 (14)	84 ± 2	430 ± 16 (10)	27 ± 7 (10)
IV	419 ± 68 (10)	78 ± 4	319 ± 38 (10)	84 ± 2	845 ± 38 (7)	39 ± 11 (7)
V	423 ± 69 (13)	79 ± 4	320 ± 63 (13)	84 ± 3	831 ± 18 (9)	39 ± 11 (9)
VI	932 ± 76 (4)	74 ± 2	710 ± 32 (4)	80 ± 1	1567 ± 5 (3)	171 ± 35 (3)
VII	753 ± 121 (7)	71 ± 5	610 ± 112 (7)	77 ± 4	1133 ± 117 (7)	155 ± 80 (7)

[a]Averages values for all conditions: pH = 7.1 ± 0.2. Values in parentheses refer to the number of samples analyzed in each condition.

Table 4
Nitrogen Concentrations for Influent and Effluent

Condition	TKN-N (mg/L)		N_{Org}-N (mg/L)		NH_4^+-N (mg/L)		NO_3^--N (mg/L)		NO_2^--N (mg/L)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
II	60.2	63.9	58.2	11.5	2.0	52.4	2.04	0.29	0.038	0
III	60.2	52.1	58.2	16.0	2.0	36.1	2.04	3.42	0.038	0.003
IV	116.7	105.6	112.3	26.8	4.4	78.8	3.68	0.88	0.028	0
V	116.7	100.8	112.3	22.7	4.4	78.1	3.68	0.88	0.028	0.003
VII	178.2	183.0	172.8	43.4	5.4	139.6	6.01	6.08	0.041	0.007

Table 5
Average Values of Solids in Influent[a]

Condition	TS (mg/L)	TVS (mg/L)	TSS (mg/L)	VSS (mg/L)
I	833 ± 27 (3)	413 ± 16 (3)	17 ± 4 (3)	18 ± 3 (3)
II	1138 ± 86 (8)	322 ± 33 (8)	44 ± 15 (8)	29 ± 13 (8)
III	1797 ± 63 (4)	913 ± 65 (4)	38 ± 12 (4)	30 ± 8 (4)
IV	3315 ± 18 (5)	1620 ± 33 (5)	59 ± 21 (5)	39 ± 5 (5)
V	3351 ± 109 (5)	1622 ± 89 (5)	86 ± 49 (5)	81 ± 51 (5)
VI	6517 ± 72 (2)	3025 ± 58 (2)	153 ± 52 (2)	128 ± 48 (2)
VII	4960 ± 120 (3)	2363 ± 76 (3)	91 ± 27 (3)	70 ± 5 (3)

[a]Values in parentheses refer to the number of samples analyzed in each condition.

Table 6
Average Values of Solids in Effluent[a]

Condition	TS (mg/L)	TVS (mg/L)	TSS (mg/L)	VSS (mg/L)
I	595 ± 57 (3)	175 ± 25 (3)	71 ± 55 (3)	23 ± 8 (3)
II	1740 ± 28 (5)	853 ± 39 (5)	38 ± 11 (5)	26 ± 10 (5)
III	1155 ± 38 (5)	304 ± 12 (5)	47 ± 21 (5)	41 ± 17 (5)
IV	2227 ± 49 (5)	588 ± 55 (5)	88 ± 26 (5)	80 ± 20 (5)
V	2273 ± 83 (7)	566 ± 78 (7)	92 ± 29 (7)	83 ± 31 (7)
VI	4363 ± 120 (2)	857 ± 75 (2)	156 ± 0 (2)	122 ± 3 (2)
VII	3186 ± 151 (3)	832 ± 61 (3)	161 ± 37 (3)	138 ± 32 (3)

[a]Values in parentheses refer to the number of samples analyzed in each condition.

Table 7
Summary of Some Design Parameters Used

Condition	VOL (g COD/ [L·d])	SOL (mg COD/ g [TVS·d])	SOR_T (mg COD/ g [TVS·d])	SOR_F (mgCOD/ g [TVS·d])	C_X (g TVS/L)
I	0.66 ± 0.09	—	—	—	—
II	0.78 ± 0.04	35.3	28.2	30.6	22.0
III	1.22 ± 0.10	52.7	40.1	43.3	23.1
IV	1.55 ± 0.10	77.5	60.8	64.8	20.0
V	2.36 ± 0.14	166.0	130.2	138.9	14.2
VI	2.88 ± 0.17	189.4	140.4	152.1	15.2
VII	2.08 ± 0.09	127.3	90.4	97.4	16.3

ied from 73 to 275 mg/L, resulting in a reduction in removal efficiency down to 77% for filtered samples, after 28 cycles.

At all the investigated conditions BA was generated and pH remained near neutrality. As to volatile acids concentration, for the assays at which influent concentrations varied from 550 to 2000 mg of COD/L, TVA values in the effluent varied from 21 to 39 mg/L, whereas in the assays at which

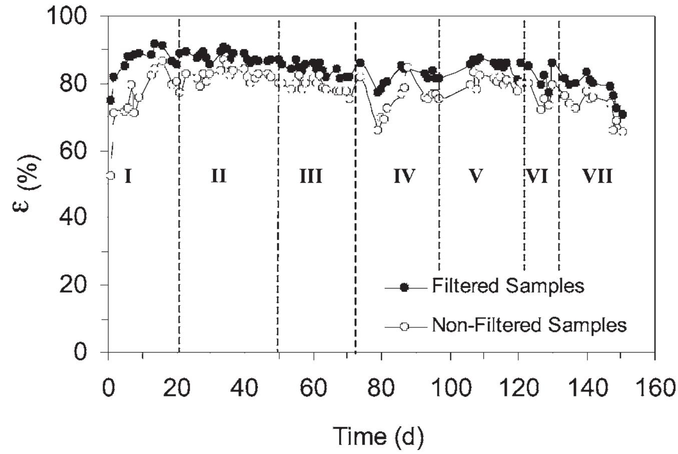

Fig. 2. Removal efficiencies of organic matter for all conditions studied.

influent concentrations were 2600 and 3600 mg of COD/L, TVA ranged from 155 ± 80 to 171 ± 3 mg/L, with a consequent reduction in the removal efficiency of organic matter.

Despite the fact that conditions V and VII presented similar organic loads of about 2.36 and 2.08 g of COD/(L·d), respectively, stability was obtained at condition V (C_I = 2000 mg of COD/L, t_C = 8 h, ε_S = 84%, effluent TVA = 39 mg/L), but not at condition VII (C_I = 2600 mg of COD/L, t_C = 12 h, ε_S = 77% and TVA accumulation), showing the importance of influent concentration and cycle length on the calculation of applied VOL (Table 7).

Figure 3 presents concentration profiles of filtered organic matter, TVA, BA, and methane at influent concentrations of 1000 and 2000 mg of COD/L and cycle lengths of 8 and 12 h. It can be seen that the ASBR submitted to the same influent concentration and different cycle lengths (C_I = 1000 mg of COD/L with t_C = 8 and 12 h, and C_I = 2000 mg of COD/L with t_C = 8 and 12 h) displayed distinct behavior throughout the cycle, despite attaining the same concentration at the end of the respective cycles. For the lowest influent concentration, 1000 mg of COD/L, the initial removal rate was higher for the longer 12-h cycle assay, whereas for the highest influent concentration, 2000 mg of COD/L, the initial removal rate was higher for the shorter 8-h cycle assay.

The reason for this behavior may be understood by analyzing the TVA profiles of the previously analyzed assays (see Fig. 3). On the whole, there is an initial accumulation followed by consumption, characterizing intermediate metabolism. At the lowest influent concentration, 1000 mg of COD/L, and the shortest cycle, 8 h, higher accumulation of volatile acids can be seen. However, this accumulation of TVA was higher for the 12-h cycle and influent concentration of 2000 mg of COD/L. Thus, highest accumulation occurred at the shortest cycle with the lowest influent concentration, and at the longest cycle with the highest influent concentration. It should be pointed out that assays were performed in the sequence

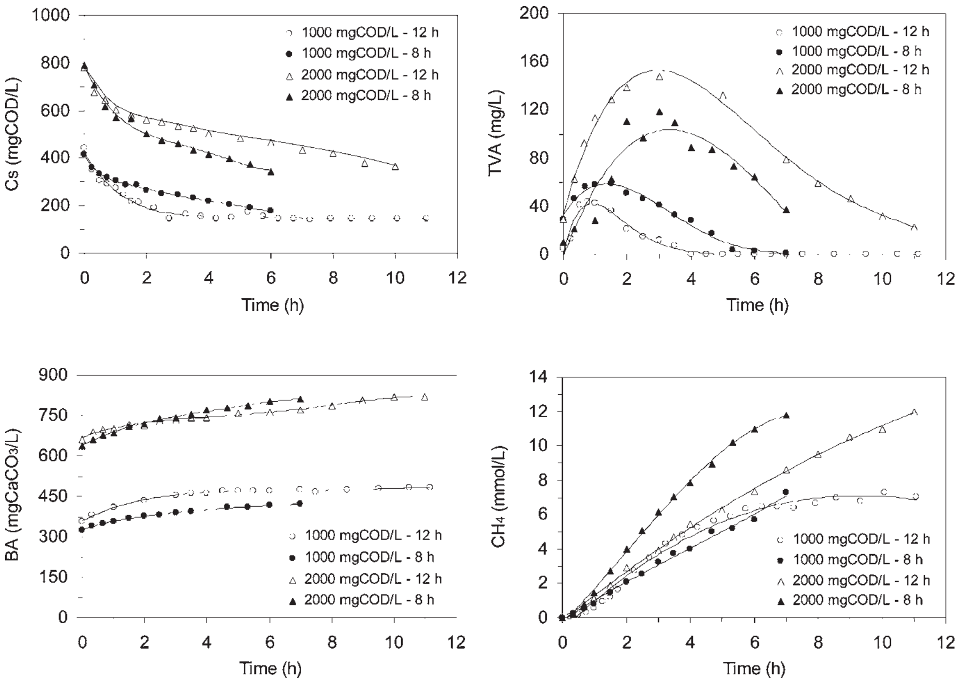

Fig. 3. Profiles of monitored variables in ASBR for some studied conditions.

1000 mg of COD/L and 12 h, 1000 mg of COD/L and 8 h, 2000 mg of COD/L and 12 h, and 2000 mg of COD/L and 8 h, therefore excluding any correlation between the ongoing discussion and assay execution. The acetic and butyric acid profiles in Fig. 4 show different increases in acid concentration with influent concentration and cycle length. The alkalinity profiles show similar behavior at these conditions analyzed, both qualitatively and quantitatively (see Fig. 3), indicating a proportional supplementation and a consequent noninfluence of this variable on the behavior at issue.

Two interesting points can be seen from the profiles of methane concentration in the biogas accumulated in the bioreactor headspace (see Fig. 3). First, there was a higher methane production with increasing influent concentration, which agrees with the stoichiometric proportion between organic matter consumed and methane produced. Second, there was a higher production rate when the cycle length was longer for an influent concentration of 1000 mg of COD/L and a lower production rate when the cycle length was shorter for an influent concentration of 2000 mg of COD/L. Accordingly, for the longer cycle, when influent concentration was 1000 mg of COD/L, and for the shorter cycle, when influent concentration was 2000 mg of COD/L, higher rates of organic matter consumption, volatile acids consumption, and methane production occurred. A possible explanation for this may be divided into two parts. For the lower influent concentration, at which volatile acid levels did not exceed 60 mg/L, a longer cycle allows the system to attain a chemical equilibrium more favorable to

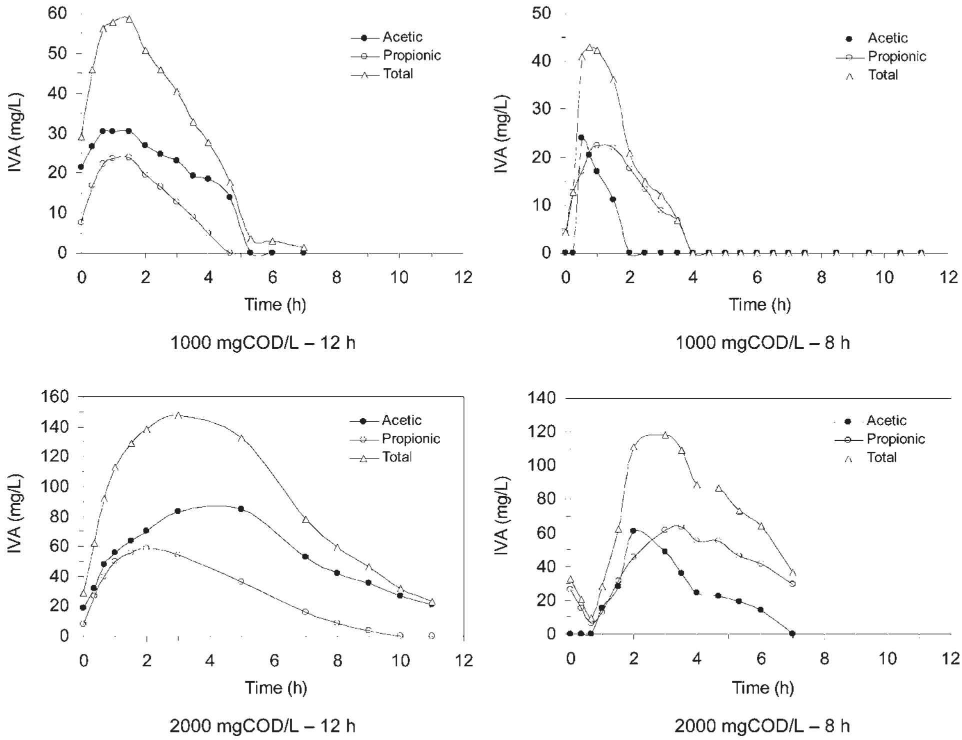

Fig. 4. Profiles of intermediate volatile acids (IVA) in ASBR for some studied conditions. The values of isobutyric, butyric, isovaleric, and valeric acids were lower than the detection method limit.

microbiologic diversity at the end of the cycle and to be better prepared for the next cycle. For the higher influent concentration, at which volatile acid levels ranged from 120 to 150 mg/L, a shorter residence time in this environment provides a more favorable condition for the sludge microorganisms, emphasizing that at each new feed an amount of alkalinity was introduced into the system. Note, however, that these levels were not sufficient to impair system efficiency and stability. Yet, imposing on the system a condition beyond the critical level (condition VI), at which volatile acid levels reached 400 mg/L (see Fig. 5), resulted in disturbance in biomass equilibrium, which remained when influent concentration was reduced (condition VII); reduction in influent concentration did not result in recovery of previous performance.

Siman et al. *(17)* studied the influence of the increase in organic load in a system containing immobilized biomass on polyurethane foam using the same inoculum and treating the same volume of 2 L of the same type of synthetic wastewater per cycle (of 8 and 12 h). Influent concentrations were 500–1800 mg of COD/L, resulting in VOLs of 1.47–5.43 g of COD/(L·d) at a biomass concentration of 25 g of TVS/L. Organic matter conversions of 74–82% were obtained for VOLs of 1.47–3.61 g of COD/(L·d), with the best

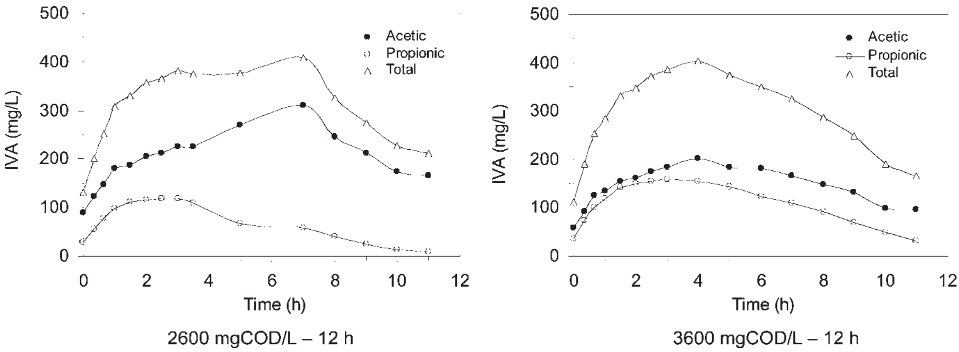

Fig. 5. Profiles of intermediate volatile acids (IVA) in ASBR for higher concentrations studied. The values of other acids were as follows: isobutyric, 4–16 mg/L; butyric, 2–8 mg/L; isovaleric, 7–22 mg/L; valeric, 1–2 mg/L.

conversion results of 79 and 81% (for nonfiltered and filtered samples, respectively) for a VOL of 3.61 g of COD/(L·d) and an SOL of 138 mg of COD/(g of TVS·d) when the influent concentration was 1800 mg of COD/L and cycle length was 12 h. This result was comparable with the best value encountered in the current work; that is, for a VOL of 2.36 g of COD/(L·d) and an SOL of 166 mg of COD/(g of TVS·d) conversions of 79 and 84% (for nonfiltered and filtered samples, respectively) were obtained when the influent concentration was 2000 mg of COD/L and cycle length was 8 h. Thus, the system containing immobilized biomass, compared with the system containing granular biomass, showed improved treatment capacity, defined by higher VOL and lower SOL, fixing the same volume treated per cycle and the same conversion at the end of the cycle. This occurs despite the lower influent concentration and a longer cycle of the system containing immobilized biomass, because the system containing granular biomass requires a residual volume for solids retention (in the settling and decant steps).

On one hand, the residual volume present in systems containing granular biomass allows the use of similar influent concentrations and volumes with shorter cycles, compared with systems containing immobilized biomass, likely owing to the dilution effect of the feed volume by the volume already present in the reactor. On the other hand, the better distribution of biomass owing to the presence of the inert support dispenses with the need for this residual volume; that is, the immobilized biomass has improved contact with the wastewater (with the aid of mechanical stirring).

It is worth pointing out that in the work of Siman et al. *(17)* similar VOLs (2.77 and 2.88 g of COD/[L·d]) but influent concentrations of 1400 and 1000 mg of COD/L and 12- and 8-h cycles, respectively, resulted in different conversions, 81 and 69%, respectively, indicating the importance of the effect of these variables on the process, independent of the resulting organic load. Moreover, at the stable conditions volatile acids values remained less than 100 mg/L, whereas at the unstable condition this value reached 500 mg/L. Both results indicate similarity between the two investigations.

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, as well as hydrogenotrophic bacilli, nonfluorescent cocobacilli and vibria, also showing equilibrium in the distribution of *Methanosaeta* sp. and *Methanosarcina* sp. genus. This indicates that the different experimental conditions did not bring about significant modifications in the biomass, considering the microbiologic techniques employed. Moreover, comparison of this microbiologic characterization of the biomass in the reactor after the experimental period with the results obtained of the sludge used as inoculum reveals no significant modifications in the biomass. This way, the results of these microbiological analyses help to confirm the investigation as a function of the different conditions implemented.

Conclusion

Analysis of the effect of organic load on the behavior of a 5-L mechanically stirred ASBR (75 rpm) treating 2 L of synthetic wastewater at concentrations ranging from 550 to 2000 mg of COD/L and a temperature of 30°C showed that the reactor presented stability at VOLs from 0.66 to 2.36 g of COD/(L·d) and cycle lengths of 8 and 12 h, at which removal efficiencies varied from 79 to 81% for nonfiltered and from 84 to 88% for filtered samples. Moreover, good solids retention was possible, despite the applied agitation and organic load, attaining biomass concentration ranging from 14 to 23 g of TVS/L.

However, operating at wastewater concentrations of 2600 and 3600 mg of COD/L and a 12-h cycle, i.e., a VOL of 2.08 and 2.88 COD/(L·d), stability could not be obtained, presenting accumulation of TVA and removal efficiency below 74% for nonfiltered samples. Moreover, for a VOL of 0.78–2.36 g of COD/(L·d), for the same influent concentration of 2000 mg of COD/L, when cycle length was reduced from 12 to 8 h, removal efficiency did not vary; however, behavior throughout the cycle was notably distinct for the different conditions. These results indicate the individual importance of influent concentration and cycle length on ASBR design, in combination with the VOL value, at which these values are considered.

Finally, the results were comparable with those shown in the work of Siman et al. *(17)* for an ASBR containing immobilized biomass (using the same inoculum) operated under similar conditions (using the same influent) in which operation was possible with higher VOLs and lower SOLs. This occurred with the ASBR containing immobilized biomass operating with a lower influent concentration and a longer cycle, owing to the improved biomasss distribution brought about by the presence of the inert support as well as the presence of a residual volume in the system containing granular biomass.

Acknowledgments

We acknowledge Dr. Baltus C. Bonse for revising the manuscript. This study was supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo (São Paulo, Brazil) (process no. 03/03.883-9 and 01/05.489-0).

Nomenclature

BA = bicarbonate alkalinity (mg of $CaCO_3$/L)
C_{ES} = filtered substrate concentration in effluent (mg of COD/L)
C_{ET} = nonfiltered substrate concentration in effluent (mg of COD/L)
C_I = nonfiltered substrate concentration in influent (mg of COD/L)
C_X = biomass concentration in bioreactor (g of TVS/L)
IVA = intermediate volatile acid concentration (mg/L)
NH_4^+-N = concentration of ammonium nitrogen (mg of NH_4^+/L)
NO_2^--N = concentration of nitrite nitrogen (mg of NO_2^-/L)
NO_3^--N = concentration of nitrate nitrogen (mg of NO_3^-/L)
N_{Org}-N = concentration of organic nitrogen (mg of N_{Org}/L)
SOL = nonfiltered specific organic load (mg of COD/[g of TVS·h])
SOR_S = filtered specific organic load (mg of COD/[g of TVS·h])
SOR_T = nonfiltered specific organic load (mg of COD/[g of TVS·h])
t_C = cycle length (h)
TKN-N = concentration of total Kjeldahl nitrogen (mg of TKN/L)
TS = total solids concentration (mg of TS/L)
TSS = total suspended solids concentration (mg of TSS/L)
TVA = total volatile acids concentration (mg/L)
TVS = total volatile solids concentration (mg of TVS/L)
V = medium volume in bioreactor (L)
V_F = feed volume in reactor per cycle (L)
VOL = volumetric organic load (mg of COD/[L·d])
VSS = volatile suspended solids concentration (mg of VSS/L)
ε_S = filtered organic matter removal efficiency in system (%)
ε_T = nonfiltered organic matter removal efficiency in system (%)

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