

Feasibility of Treating Swine Manure in an Anaerobic Sequencing Batch Biofilm Reactor With Mechanical Stirring

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Abstract

Anaerobic sequencing batch reactors containing granular or flocculent biomass have been employed successfully in the treatment of piggery wastewater. However, the studies in which these reactors were employed did not focus specifically on accelerating the hydrolysis step, even though the degradation of this chemical oxygen demand (COD) fraction is likely to be the limiting step in many investigations of this type of wastewater. The mechanically stirred anaerobic sequencing batch biofilm reactor offers an alternative for hastening the hydrolysis step, because mechanical agitation can help to speed up the reduction of particle sizes in the fraction of particulate organic matter. In the present study, a 4.5-L reactor was operated at 30°C, with biomass immobilized on cubic polyurethane foam matrices (1 cm of side) and mechanical stirring provided by three flat-blade turbines (6 cm) at agitation rates varying from 0 to 500 rpm. The reactor was operated to treat

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diluted swine waste, and mechanical stirring efficiently improved degradation of the suspended COD. The operational data indicate that the reactor remained stable during the testing period. After 2 h of operation at 500 rpm, the suspended COD decreased by about 65% (from 1500 to 380 mg/L). Apparent kinetic constants were also calculated by modified first-order expressions.

Index Entries: Anaerobic sequencing batch reactor; anaerobic sequencing batch biofilm reactor; mechanical stirring; piggery wastewater; solids removal; swine manure.

Introduction

Swine manure is widely known to be a high-strength wastewater with a pollutant organic load approx 250 times higher than domestic sewage. Its treatment, moreover, requires overcoming the difficulties of large amounts of residues and a high percentage of solids. Separating the liquid and solid phases facilitates secondary treatment processes, such as the anaerobic ones. Several types of anaerobic reactors have been tested in the treatment of diluted piggery wastewater: fixed-film reactor (1,2), anaerobic filter (3), tubular reactor (4), continuous stirred tank reactor (CSTR) with suspended particle attached-growth biomass (5), and anaerobic sequencing batch reactor (ASBR) (6–9).

ASBRs containing granular or flocculent biomass have been employed successfully for treating piggery wastewater (6–9). However, those studies did not clearly focus on accelerating the hydrolysis step, although degradation of the chemical oxygen demand (COD) fraction is often possibly the limiting step in studies involving this type of wastewater, which usually contains between 0.5 and 3.0% of total solids (TS) in its raw form (10).

The mechanically stirred anaerobic sequencing batch biofilm reactor (ASBBR) may offer an alternative for speeding up the hydrolysis step, for mechanical agitation may help to hasten the reduction of particle sizes of particulate organic matter. Particle size is related directly to the rate of hydrolysis, because the greater the surface area, the better the contact of organic matter with the extracellular enzymes responsible for this step of the anaerobic process (11). The ASBBR configuration used in the present study has already been proposed (12) and tested with synthetic wastewaters (12–14) and partially soluble synthetic wastewater (15,16), showing promising results in every case.

Polyurethane foam was used as support material for biomass attachment in a CSTR with suspended particles for the treatment of swine manure (10), and it was found that the startup period was very short (3 wk) and that the process remained stable throughout the study, responding readily to changes in the volatile solids loading rate and in the cycle time. Very low volatile acid effluent concentrations were also observed.

The work reported on here consisted of evaluating the performance of an ASBBR mechanically stirred and containing polyurethane foam as support material in the treatment of diluted swine waste.

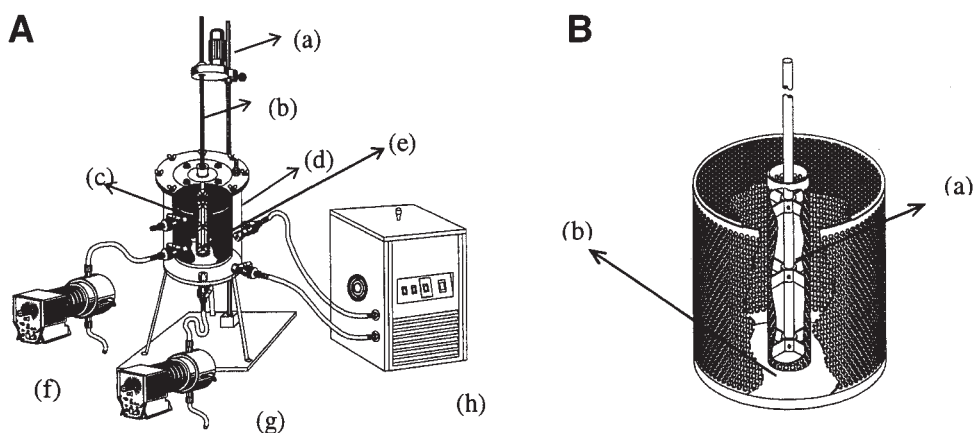


Fig. 1. (A) Scheme of bench-scale ASBBR: (a) motor; (b) agitation shaft; (c) basket containing biomass; (d) water jacket; (e) central hole for agitation shaft and impellers; (f) and (g) feed and discharge positive displacement pumps; (h) thermostatic bath (to feed water jacket). (B) Perforated basket located inside reactor to confine polyurethane foam matrices: (a) central hole containing agitation shaft with three impellers; (b) external portion containing immobilized biomass.

Materials and Methods

The ASBBR (Fig. 1) was constructed with a 22-cm-diameter Plexiglas tube with a useful volume of 4.5 L. The biomass was immobilized on cubic polyurethane foam matrices (1-cm sides; total mass = 31 g), which were placed in a perforated basket (diameter = 18 cm; Fig. 2). Mechanical stirring was done by three flat-blade turbines (diameter = 6 cm) at agitation rates varying from 0 to 500 rpm. The experiments were carried out at $30 \pm 1^\circ\text{C}$, and the temperature in the reactor was kept constant by a water jacket.

The substrate was swine manure, whose characteristics are given in Table 1. These characteristics correspond to the wastewater already diluted and screened using a 2-mm sieve.

The reactor's cycle length was 24 h with the feeding and discharge steps lasting 10 min each. The content in the reactor was substituted completely in each cycle. The reactor was seeded with a mixture of granular sludge from a full-scale upflow anaerobic sludge blanket (UASB) reactor treating slaughterhouse wastewater and flocculent sludge from a laboratory scale UASB reactor treating piggery wastewater (70/30% in volume, respectively). This ratio was chosen owing to the availability of each inoculum. The granules were macerated and mixed with the flocculent sludge, and this mixed inoculum was then kept in contact with the foam matrices for 24 h, after which the cubic matrices were placed in the perforated basket. The foam was not changed between the tests and was inoculated just once at the beginning of the experiment.

Chemical oxygen demand (COD), total volatile acids (TVA), bicarbonate alkalinity, and solids were determined according to the *Standard*

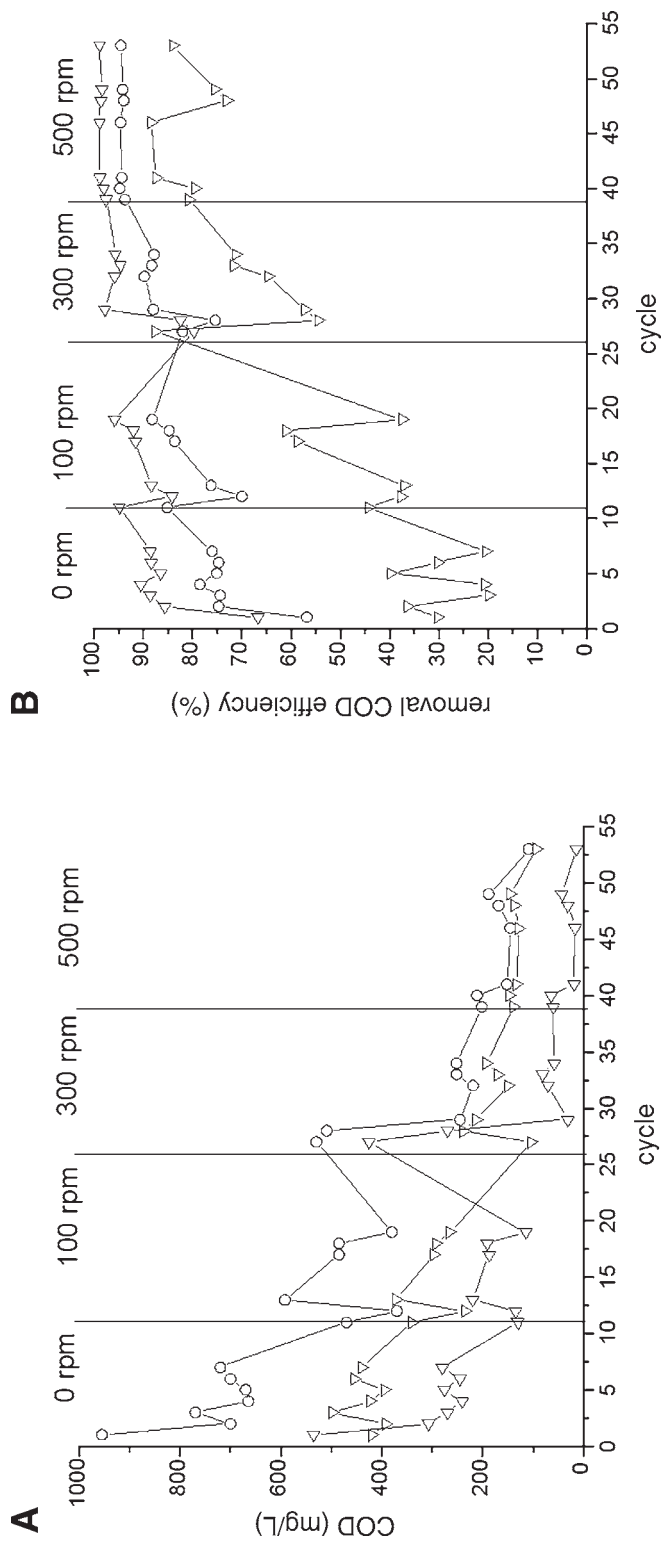


Fig. 2. Reactor performance according to COD degradation. (A) Effluent COD: (○) total, (▽) filtered, and (<▽) suspended; (B) COD removal efficiency: (○) total, (▽) filtered, and (<▽) suspended.

Table 1
Characteristics of (Diluted) Piggery Wastewater

Parameter ^a	Minimum	Maximum	Average \pm SD
Total COD (mg/L) ^b	1233	4044	2633 \pm 565
TS (g/L)	0.84	3.08	2.11 \pm 0.46
TVS (g/L)	0.60	3.08	1.79 \pm 0.47
TSS (g/L)	0.85	2.40	1.45 \pm 0.44
VSS (g/L)	0.38	2.10	1.26 \pm 0.42

^aTS, total solids; TVS, total volatile solids; TSS, total suspended solids; VSS, volatile suspended solids.

^bSeventy-five percent suspended COD.

Methods for Examination of Water and Wastewater (17). Samples of volatile fatty acids (VFA) were analyzed by gas chromatography, using a gas chromatograph HP6890 with a flame ionization detector at 300°C and an HP INNOWAX column (30 m \times 0.25 mm \times 0.25 μ m). The injector temperature was maintained at 250°C; the oven was kept at 100°C for 3 min and then heated in 5°C/min steps to 180°C, where it was held for 5 min. Total protein was quantified by a modified Lowry's method (18). Carbohydrate analyses were carried out according to a modified method of Dubois (19,20). The total amount of lipids was quantified by an adaptation (20) based on the original methodology proposed by Postma and Stroes (21).

To quantify the biomass on the support, five cubic foam matrices were sampled from the reactor and put in a flask containing glass beads and 20 mL of water. The flask was then sealed and agitated manually for about 20 min, or until all the adhered biomass was separated from the foam. Then the liquid was separated from the foam and the glass beads, transferred to a porcelain capsule, and subjected to conventional TS and total volatile solids analyses (17). The foam was transferred to another capsule, where it was kept at 110°C for 24 h to dry out completely.

The degradation kinetics were evaluated through temporal profiles of COD fitted by modified first-order expressions.

Results and Discussion

The reactor was operated for 55 d (55 consecutive cycles), with the agitation rate varying from 0 to 500 rpm, and its performance was evaluated throughout these phases. Figure 3 shows the COD degradation results.

An analysis of the plots in Fig. 2 indicates that all the COD fractions were consumed from the beginning of the operation. The high-efficiency removal of suspended organic matter (suspended COD) in the operating condition without agitation was probably owing to the initial physical retention or sedimentation. The effluent COD values decreased from the start of the operation up to 100 rpm; these values declined more sharply at 300 rpm, further improving the removal efficiencies of this organic matter fraction.

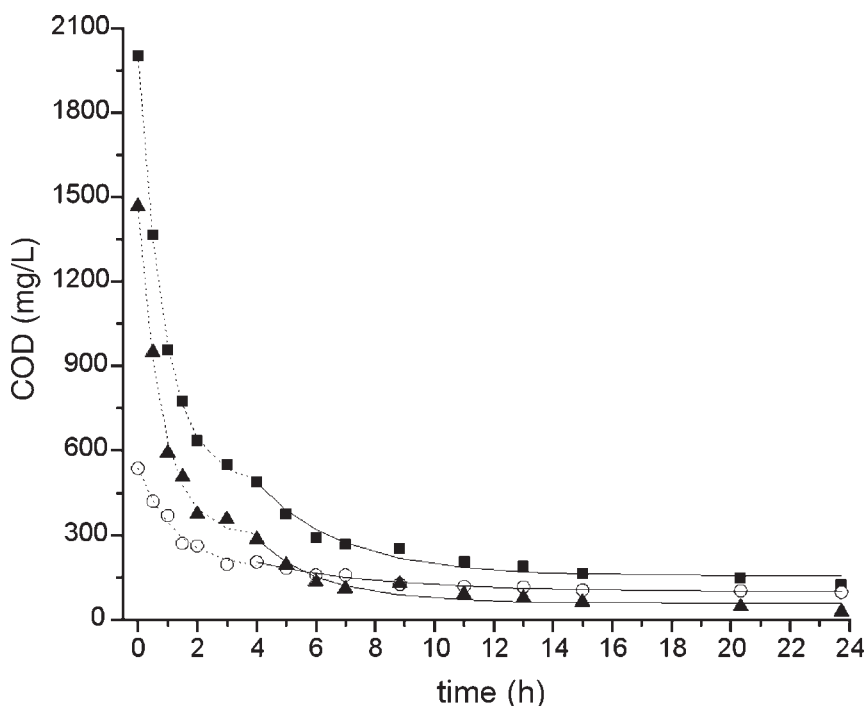


Fig. 3. Temporal profiles of COD: (■) total, (○) filtered, and (▲) suspended.

The effluent filtered COD decreased continuously as the agitation rate increased. This tendency is clearly illustrated in the plot in Fig. 2B, which shows a considerable enhancement of the removal efficiency of filtered COD from about 30% (no agitation) to >70% (at 500 rpm).

The effluent bicarbonate alkalinity (average = 339 ± 65 mg of CaCO_3/L) was consistently higher than the influent (average = 102 ± 27 mg of CaCO_3/L), indicating the good stability of the process. The TVA concentrations were consistently lower than 200 mg/L (average influent = 172 ± 36 mg of HAc/L and average effluent = 108 ± 40 mg of HAc/L), also indicating the absence of reactor acidification and confirming the good stable operating conditions.

Table 2 gives the solids removal efficiency values, which indicate that the average efficiencies of the four parameters rose as the agitation rate increased. However, this increase was more significant in the case of TS than in that of suspended solids, leading to the conclusion that the removal of dissolved solids increased, which is congruent with the considerable increase in filtered COD removal depicted in Fig. 2B.

The temporal profiles of COD and volatile acids along the batch cycle were obtained during the fifty-fifth cycle (under 500 rpm). Figure 3 shows the profiles for total, filtered, and suspended COD fractions, as well as the respective kinetic fittings.

Table 2
Minimum, Maximum, and Average Removal Efficiencies
of Total and Suspended Solids at Each Agitation Rate

Parameter ^a	Average efficiency removal (%)			
	No agitation	100 rpm	300 rpm	500 rpm
TS	52	65	57	76
TVS	54	67	73	76
TSS	73	81	79	84
VSS	73	77	79	82

^aSee Table 1 for definitions of abbreviations.

Table 3
Kinetic Coefficients Obtained
by Fittings With Modified First-Order Expressions

COD fraction	k_1^{app} (h ⁻¹)		S_R (end of cycle) (mg/L)
	0–4 h	4–24 h	
Total	1.11 ± 0.03	0.34 ± 0.05	153 ± 13
Filtered	0.75 ± 0.11	0.24 ± 0.02	97 ± 3.2
Suspended	1.25 ± 0.08	0.43 ± 0.08	57 ± 11

The three profiles revealed two distinct decay tendencies, one from 0 to 4 h and the other from 4 to 24 h. The first part of the profile was fitted by the modified first-order kinetic expression, as adopted previously (13,16):

$$S = S_R + (S_o - S_R)\exp(-k_1^{\text{app}}t) \quad (1)$$

The second part of the profile (4–24 h) was fitted by a similar expression, but with a term of time delay (t_o in hours):

$$S = S_R + (S_o - S_R)\exp[-k_1^{\text{app}}(t - t_o)] \quad (2)$$

In Eqs. 1 and 2, t is time (min); S and S_o are, respectively, the substrate concentration (as COD) at t and t_o (initial time, assumed as zero for Eq. 1 and set at 4 h in Eq. 2; S_R is the residual COD (mg/L); and k_1^{app} (h⁻¹) is the apparent first-order kinetic constant.

Table 3 provides the kinetic coefficients. In the three cases, the values of k_1^{app} for the second part of the profile (4–24 h) were about 70% lower than the ones obtained for the first part (0–4 h). This fact is likely owing to the more complex nature of the organic matter available in the media, detected in the analyses of proteins, carbohydrates, and lipids.

The temporal profiles also revealed two different tendencies in the individual substrates (carbohydrates, proteins, and lipids), as can be seen in Fig. 4. Table 4 gives the estimated k_1^{app} values.

It is interesting to note the sharp drop in the lipid profile at the beginning of the profile. Because lipids are usually some of the most difficult

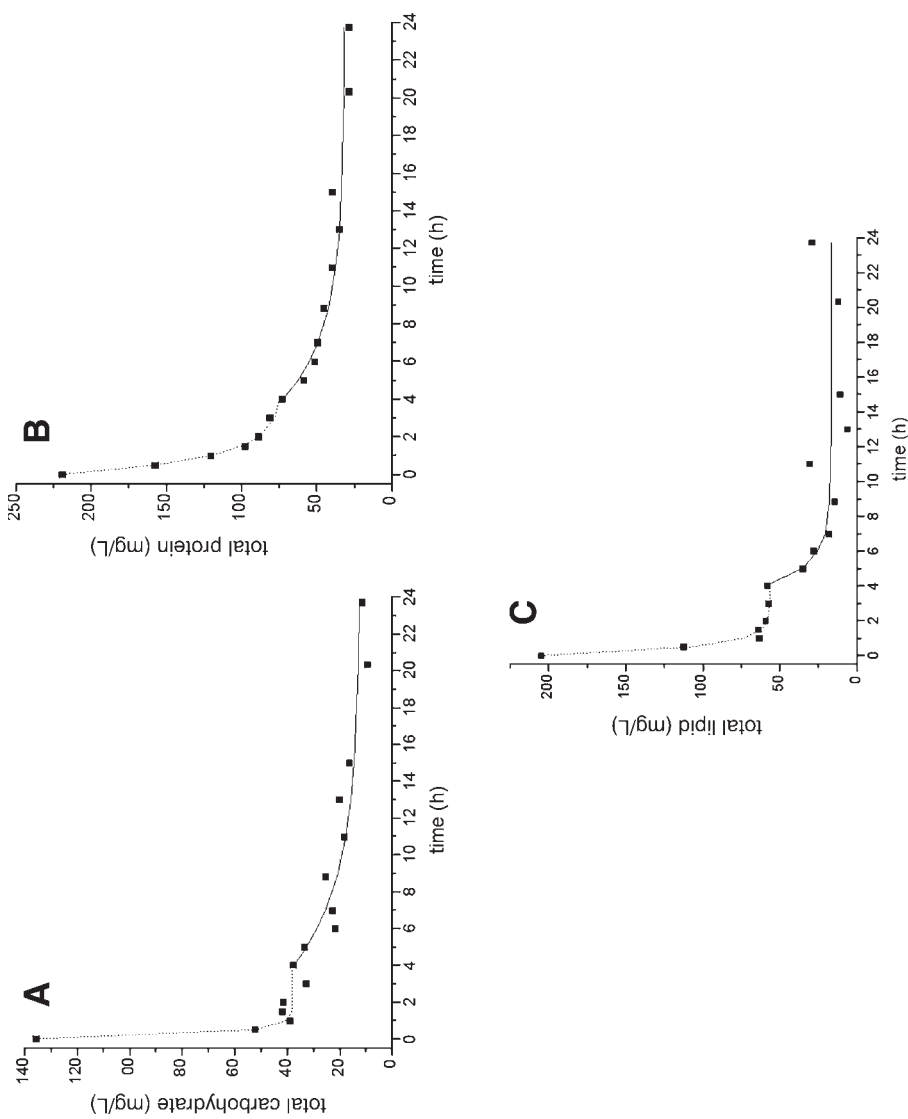


Fig. 4. Temporal profiles of individual substrates: (A) carbohydrates, (B) proteins, and (C) lipids.

Table 4
Kinetic Coefficients Obtained
by Fitting Individual Substrates Data With Modified First-Order Expressions

Substrate	$k_1^{\text{app}} \text{ (h}^{-1}\text{)}$		S_R (end of cycle) (mg/L)
	0–4 h	4–24 h	
Carbohydrates	3.88 ± 0.50	0.21 ± 0.07	12 ± 2.8
Proteins	1.12 ± 0.04	0.28 ± 0.05	31 ± 2.2
Lipids	2.17 ± 0.22	0.79 ± 0.34	17 ± 3.4

substrates to degrade, a hypothesis that may explain this phenomenon is the occurrence of their initial adsorption on the biomass (22). It was stated (23) that this is an important process insofar as it may provide the primary removal mechanism. The plateau after this initial adsorption (from 1 to 4 h) possibly corresponds to the gradual oxidation of the fatty acid chains. Because the method employed here quantifies total lipids independently of chain length, the lipid content was probably undergoing continuous consumption, and because this method does not distinguish the different fatty chains, this consumption is not visible in the profile. This lipids' kinetic behavior may be the major factor responsible for the COD profile, which also presented two distinct tendencies, and these were probably the main contributing factors for the amount of organic matter present in the wastewater tested. It is worth noting that in the first phase of the profile (0–4 h), protein was the limiting substrate, and its kinetic constant was reflected in the overall constant (for total COD). In the second phase (4–24 h), carbohydrates appeared to be the limiting reactants. On the other hand, it is interesting that the degradation of the lipids was never the limiting step.

In this sense, the constant calculated for COD basically reflects in the first step the limitation imposed by the proteins. In the second step, other factors were more important: possibly, other intermediate substances not analyzed, since VFA were present in low concentrations after 4 h. Moreover, the proteins were also the major contributors to the residual.

As in the case of the COD, the second part of the profile (4–24 h) displayed a marked decline in k_1^{app} values, probably for the aforementioned reason, i.e., the type of organic matter available.

Figure 5 illustrates the temporal profiles of VFA, which indicate that no accumulation occurred along the cycle except for isobutyric acid, which showed an increase between the beginning of the cycle and 2 h. After 2 h, the net accumulation was zero, which may indicate that, after 2 h, the degradation rate began to slow down in response to two factors: (1) lower substrate bioavailability, as shown in the temporal profiles plotted in Figs. 2 and 3; (2) most of the available organic matter consisting of less readily degradable substances.

Another important datum is the ratio of mass of microorganisms (measured as volatile solids) per mass of support. At the end of the opera-

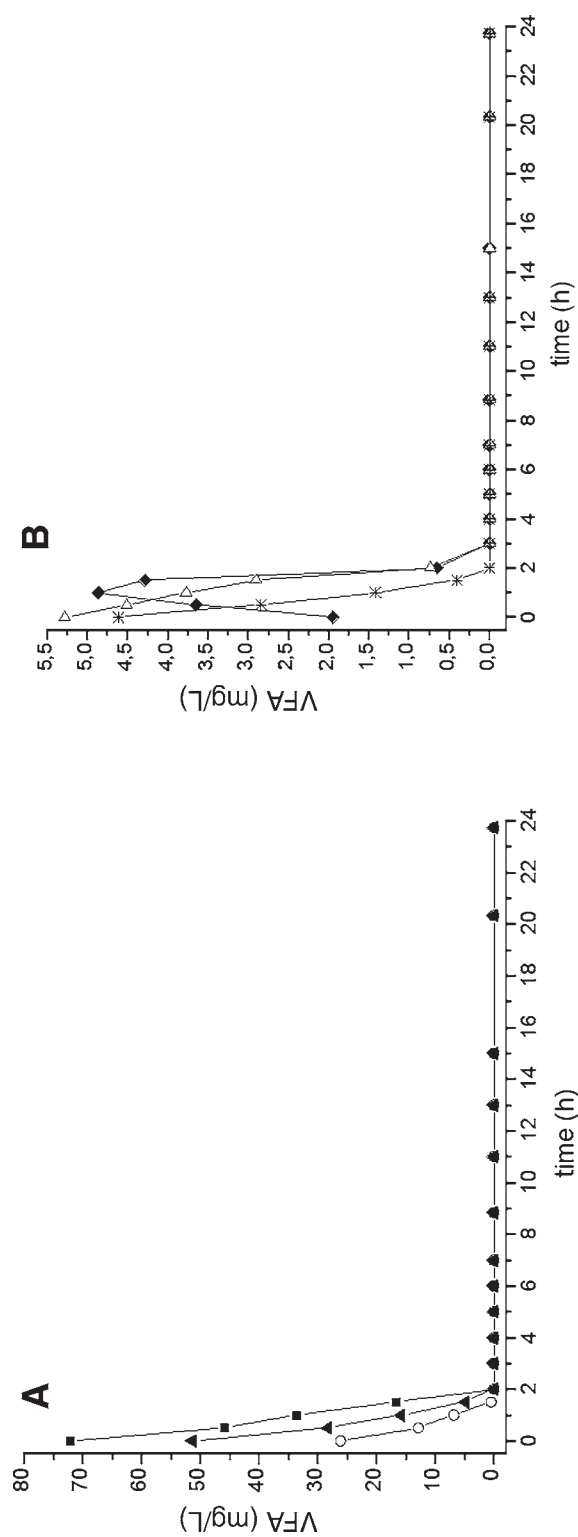


Fig. 5. Temporal profiles of VFA: (A) (■) acetic, (○) propionic, and (▲) butyric acids; (B) (◆) isobutyric, (▷) isovaleric, and (*) valeric acids.

tion, this ratio was 1.02 mg of VS/mg of foam, a value considered suitable when compared with that of similar reactors (13).

Conclusion

It was demonstrated that the mechanically stirred ASBBR is a viable instrument for treating diluted swine waste. The operational data indicated that the reactor remained stable during the period tested, which was confirmed by the production of bicarbonate alkalinity and the low concentrations of TVA, as well as the good COD and solids removal efficiencies.

According to the temporal profile, the suspended COD dropped by about 65% (from 1500 to about 380 mg/L) in 2 h of operation. In this sense, mechanical stirring proved to improve efficiently the degradation of suspended COD, one of the major problems in treating this type of wastewater.

The cycle length applied to obtain the temporal profiles seemed very long with the agitation rate employed. Note that the results obtained with the ASBBR depend on a combination of cycle length and agitation rate, which are inevitably dictated by operational costs in a full-scale installation. In our study, e.g., the power density (power utilized per unit of liquid volume) varied from <180 to about 310 W/m³ when the agitation rate was increased from 100 to 500 rpm.

The results of our study demonstrate that depending on the strength of the wastewater and on operational costs, the ASBBR can be used as a single anaerobic step or as part of a major system. In the first case, an operational strategy that might be employed to avoid a lack of substrate and reduce costs is to lower gradually the agitation rate along the cycle time. In the second case, the ASBBR could be useful for an initial process to decrease the amount of particulate organic matter before the effluent passes on to another anaerobic reactor. This strategy may preclude several common operational problems that normally occur owing to the presence of high percentages of solids and may also significantly decrease the time required to achieve the desired efficiency.

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