Effect of specific feed volume on the performance of an anaerobic sequencing batch biofilm reactor (AnSBBR) with circulation treating different wastewaters under different organic loads

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Efecto del volumen de alimentación específico sobre el comportamiento de reactores de biofilms de lotes secuenciales anaerobios con recirculación tratando aguas residuales bajo diferentes cargas orgánicas

Efecte del volum d'alimentació específic sobre el comportament de reactors de biofilms de lots seqüencials anaerobis amb recirculació tractant aigües residuals sota diferents càrregues orgàniques

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RESUMEN

El objetivo de este trabajo es el estudio del comportamiento de dos reactores de lotes secuenciales con biomasa inmovilizada (AnSBBR) en función de la relación entre el volumen del medio tratado en cada ciclo y el volumen total del medio de reacción. Los reactores, en los que la mezcla se consigue mediante recirculación de la fase líquida, se mantuvieron a 30 ± 1°C y trataron diferentes aguas residuales en ciclos de 8 horas. Las condiciones operacionales impuestas tienen el objetivo de investigar si el hecho de mantener un volumen residual en el reactor afecta, al final de cada ciclo, la eficiencia y estabilidad del proceso, además de verificar estos efectos para diferentes tipos de aguas residuales y de cargas orgánicas. El primer reactor, con un volumen útil de 2,5 L, trató suero de queso con una carga orgánica de 12 g DQO·L^{-1}·d^{-1} y mostró una calidad de efluentes similar bajo las cuatro condiciones de operación: renovación del 100, 70, 50 y 25% de su volumen útil en cada ciclo. Si bien la reducción en el volumen renovado no afectó significativamente la calidad del efluente, en términos cuantitativos esta reducción comportó un aumento en la cantidad de materia orgánica eliminada por el primer reactor. El segundo reactor, con un volumen útil d'1,8 L, trató agua residual sintética con cargas orgánicas de 3 y 5 g DQO·L^{-1}·d^{-1}, operando bajo dos condiciones para cada carga: renovación del 100 y 50% de su volumen útil. Para una carga orgánica de 3 g DQO·L^{-1}·d^{-1}, los resultados muestran que tanto la calidad del efluente como la cantidad de materia orgánica eliminada por el segundo reactor fueron independientes del volumen tratado por ciclo. Al operar con una carga orgánica de 5 g DQO·L^{-1}·d^{-1}, la reducción en el volumen renovado no afectó la cantidad de materia orgánica eliminada por el reactor, pero la calidad de los efluentes mejoró durante la operación del reactor con la descarga total de su volumen. En general, los resultados muestran la estabilidad del proceso bajo todas las condiciones, evidenciando la flexibilidad del reactor y el potencial de aplicar esta tecnología en el tratamiento de diferentes tipos de aguas residuales.

Palabras clave: suero de queso, agua residual sintética, AnSBBR, relación entre volumen tratado y volumen total, carga orgánica.

SUMMARY

The objective of this research was to study the behavior of two anaerobic sequencing batch reactors, containing immobilized biomass (AnSBBR), as a function of the ratio of the volume of treated medium in each cycle to the total volume of reaction medium. The reactors, in which mixing was accomplished by recirculation of the liquid phase, were maintained at 30 ± 1 °C and treated different wastewaters in 8-h cycles. The operational conditions imposed had the objective to investigate whether maintenance of a residual volume in the reactor would affect, at the end of each cycle, process efficiency and stability, as well as to verify the intensity of the effect for different types of wastewaters and organic loading rates. The first reactor, with work volume of 2.5 L, treated reconstituted cheese whey at an organic loading rate of 12 g COD·L^{-1}·d^{-1} and presented similar effluent quality for the four conditions under which it was operated: renewal of 100, 70, 50 and 25 % of its work volume at each cycle. Despite the fact that reduction in the renewed volume did not significantly affect effluent quality, in quantitative terms, this reduction resulted in an increase in the amount of organic matter removed by the first reactor. The second reactor, with work volume of 1.8 L, treated synthetic wastewater at organic loading rates of 3 and 5 g COD·L^{-1}·d^{-1} and operated under two conditions for each loading: renewal of 100 and 50

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% of its work volume. At the organic loading rate of 3 g COD·L^{-1}·d^{-1}, the results showed that both effluent quality and amount of organic matter removed by the second reactor were independent of the treated volume per cycle. At the organic loading rate of 5 g COD·L^{-1}·d^{-1}, although the reduction in the renewed volume did not affect the amount of organic matter removed by the reactor, effluent quality improved during reactor operation with total discharge of its volume. In general, results showed process stability under all conditions, evidencing reactor flexibility and the potential to apply this technology in the treatment of different types of wastewater.

Keywords: cheese whey; synthetic wastewater; AnSBBR; ratio treated volume to total volume; organic loading rate.

RESUM

L'objectiu d'aquest treball és l'estudi del comportament de dos reactors de lots seqüencials amb biomassa immobilitzada (AnSBBR) en funció de la relació entre el volum del medi tractat a cada cicle i el volum total del medi de reacció. Els reactors, en els que la barreja s'aconsegueix mitjançant recirculació de la fase líquida, es mantingueren a 30 ± 1ºC i tractaren diferents aigües residuals en cicles de 8 hores. Les condicions operacionals imposades tenen l'objectiu d'investigar si el fet de mantenir un volum residual en el reactor afecta, al final de cada cicle, l'eficiència i estabilitat del procés, a més de verificar aquests efectes per a diferents tipus d'aigües residuals i de càrregues orgàniques. El primer reactor, amb un volum útil de 2,5 L, tractà xerigot de formatge amb una càrrega orgànica de 12 g DQO·L-1·d-1 i mostrà una qualitat d'efluents similar sota les quatre condicions d'operació: renovació del 100, 70, 50 i 25% del seu volum útil a cada cicle. Tot i que la reducció en el volum renovat no afectà significativament la qualitat de l'efluent, en termes quantitatius aquesta reducció comportà un augment en la quantitat de matèria orgànica eliminada pel primer reactor. El segon reactor, amb un volum útil d'1,8 L, tractà aigua residual sintètica amb càrregues orgàniques de 3 i 5 g DQO·L-1·d-1, operant sota dues condicions per a cada càrrega: renovació del 100 i 50% del seu volum útil. Per a una càrrega orgànica de 3 g DQO·L-1·d-1, els resultats mostren que tant la qualitat de l'efluent com la quantitat de matèria orgànica eliminada pel segon reactor foren independents del volum tractat per cicle. En operar amb una càrrega orgànica de 5 g DQO·L-1·d-1, la reducció en el volum renovat no afectà la quantitat de matèria orgànica eliminada pel reactor, però la qualitat dels efluents millorà durant l'operació del reactor amb la descàrrega total del seu volum. En general, els resultats mostren la estabilitat del procés sota totes les condicions, evidenciant la flexibilitat del reactor i el potencial d'aplicar aquesta tecnologia en el tractament de diferents tipus d'aigües residuals.

Mots clau: xerigot de formatge, aigua residual sintètica, AnSBBR, relació entre volum tractat i volum total, càrrega orgànica.

INTRODUCTION

Anaerobic process technology experienced significant advances in the seventies as a result of the energy crisis which demanded low-cost alternatives for the treatment of wastewaters. Novel reactor configurations were designed that enabled high organic matter removal efficiency in increasingly smaller tanks and increasingly shorter times. These configurations include the anaerobic sequencing batch reactor (ASBR) and the anaerobic sequencing batch reactor containing immobilized biomass (AnSBBR – Anaerobic Sequencing Batch Biofilm Reactor). The latter is the focus of this research. Advantages of this reactor include good solids retention, efficient operational control, relatively high organic matter removal efficiency, operational simplicity and ability to treat different sanitary and industrial wastewaters. In addition, utilization of immobilized biomass allows eliminating the sedimentation step; an interesting advantage considering the fact that the sedimentation step may often exceed 25% of the total cycle length (Dugba & Zhang, 1999). Another important feature of this reactor configuration, when mixing is provided by recirculation of the liquid phase, is the increased operational flexibility related to the volume to be treated. This volume can be increased or reduced according to the capacity of the side reservoir (Camargo *et al.*, 2002; Orra *et al.*, 2004; Ramos *et al.*, 2003).

Increasingly more reliable operation strategies have been developed since the birth of the AnSBBR. The main objective of these strategies is to enable treatment with stricter control on process stability (Demirel *et al.*, 2005). Changes in operational conditions, such as longer feed period, or incomplete discharge of the reactor at the end of each cycle, result in dilution of the influent of the subsequent cycle. Hence, volatile acids, intermediate of anaerobic metabolism, will not reach high values along the cycle and the system will be more stable and flexible (Angenent & Dague, 1995; Zaiat *et al*., 2001).

There are several works focusing on the effect of feed time on the behavior of anaerobic sequencing batch reactors. Suthaker *et al*. (1991), using five lab-scale ASBRs to treat a glucose-based synthetic substrate with concentration of 35 gCOD.L^{-1}, observed that the increase in feed time resulted in an increase in the organic matter removal efficiency. Bagley & Brodkorb (1999) used a lab-scale ASBR to treat a glucose solution with organic loading rates of 1 and 2 gCOD.L^{-1}.d^{-1}, and observed that short feed times caused accumulation of volatile acids in the reactor, mainly propionic acid. On the other hand, longer feed times caused a reduction in volatile acids concentration in the effluent of the reactor and stability was reached more rapidly. Shizas and Bagley (2002) studied the effect of influent concentration, cycle length and feed time/cycle length ratio on the performance of an ASBR treating a glucose-based wastewater, and found that adopting longer feed times minimized accumulation of volatile acids along the cycle and increased reactor stability.

However, in contrast with feed time, studies focusing on the influence of the relation between the volume of wastewater treated in each cycle and the total volume of reaction medium on reactor performance are still scarce. This relation can be considered an analogue of the "specific feed rate" (Q/V) in continuous systems. Bezerra *et al*. (2005) studied the relation treated volume to total volume on the behavior of a mechanically stirred AnSBBR treating synthetic wastewater, and observed a slight increase in performance when the reactor was operated with renewal of more than 50 % of its total volume in each cycle. Chang *et al*. (1994) assessed the performance of an ASBR in relation to the volume renewed in each cycle in the treatment of sludge from a sanitary wastewater treatment plant. The reactor operated under two conditions: cycle length of 3 and 4 hours, with renewal of 30 and 40 % of its volume in each cycle, respectively, so as to maintain a constant applied organic loading rate (OLR). The relation between the renewed volume and total volume of medium did not affect stability and performance of the reactor, which attained an efficiency of organic matter removal for filtered samples in the effluent above 90 %.

Within this context the objective of this research was to assess the effect of the initial dilution of the influent on the stability and performance of two anaerobic sequencing batch reactors, in which mixing was accomplished by recirculation of the liquid phase. The reactors treated cheese whey and synthetic wastewater and dilution was obtained by changing the influent volume fed per cycle in relation to the total volume of reaction medium in the reactor under different OLRs.

MATERIALS AND METHODS

Experimental set-up

Two reactors of identical configuration but of different size and operated independently (denominated reactor I and II) were used in the experiments. A scheme of the experimental setup, used for operating both reactors, is depicted in Figure 1.

Reactors I and II, with total capacity of 3.8 and 2.7 L, respectively, consisted of a cylindrical column with the following dimensions: height of 540 and 400 mm for reactors I and II, respectively, external diameter of 100 mm and wall thickness of 3.5 mm. The reactors were provided with an automatic unit for feeding, discharge and recirculation of the liquid phase. The recirculation system comprised *(1)* a side reservoir with total capacity of 2.1 and 0.9 L, for reactors I and II, respectively, consisting of a cylindrical acrylic container with the following dimensions: height of 300 and 400 mm, external diameter of 100 and 60 mm, for reactors I and II, respectively, and a wall thickness of 3.5 mm; and *(2)* a peristaltic pump with a maximum capacity of 30 $L.h^{-1}$. A 100-mL measuring cylinder was attached to the recirculation system for flow rate measurements. Feeding and discharge were performed using diaphragm pumps equipped with automatic timers. The chamber in which the reactor remained was kept at 30 ± 1 ºC by a heating system composed of resistances and fans, as well as a temperature sensor and controller.

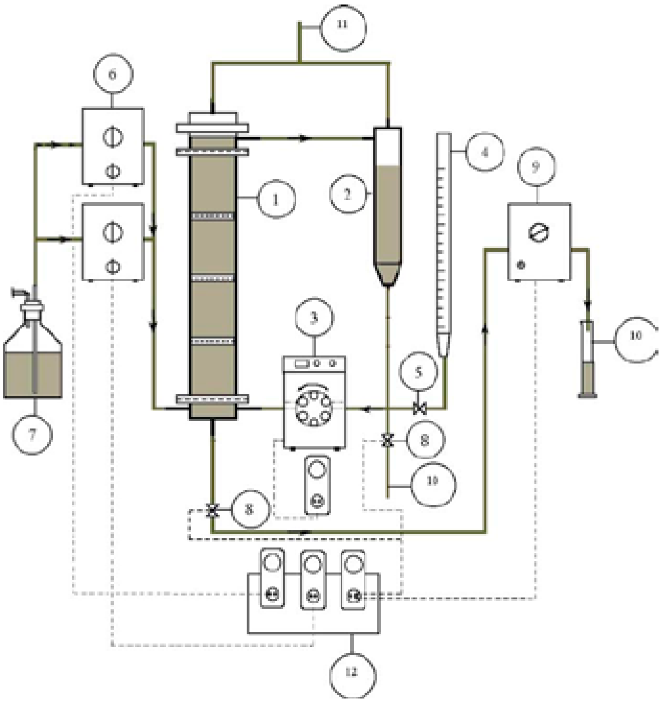

Figure 1 – Scheme of the system used for the treatment of cheese whey and synthetic wastewater

[1 – reactor containing immobilized biomass; 2 – side reservoir; 3 – recycle pump; 4 – flow meter; 5 – valve; 6 – feed pump; 7 – wastewater reservoir; 8 – discharge valves; 9 – discharge pump; 10 – effluent outlet; 11 – biogas outlet; 12 – control unit; —— hydraulic lines; ----- power lines].

Inert support and inoculum

As immobilizing inert support, in both reactors, 1-cm polyurethane foam cubes were used. The support was placed between perforated stainless steel plates, which divided the height of the reactors in five parts to avoid bed compacting. A 20-mm compartment at the bottom of the reactor allowed enhanced distribution of the wastewater, preventing in this way formation of preferential routes. At the upper part of the reactor a 40-mm region functioned as a biogas collector (CH_4 and CO_2). The inoculum used in all experiments came from an upflow anaerobic sludge blanket reactor treating wastewater from a poultry slaughter-house. Total volume of reaction medium in the reactor-reservoir system amounted to 2.5 and 1.8 L, in reactor I and II, respectively.

Wastewater

The synthetic wastewater of reactor I was prepared by dissolving dehydrated cheese whey in tap water; experimentally, 1 g of dehydrated whey corresponded to about 1 g COD. The dehydrated cheese whey consisted of proteins (11 %), carbohydrates (79 %), lipids (1 %), mineral salts (7 %) and moisture (2 %). In addition to cheese whey, the influent was supplemented with sodium bicarbonate and other salts at the following concentrations, based on a cheese whey concentration in the influent of 4000 $mgCOD.L^{-1}$: $NaHCO_3$ (2000 $mg.L^{-1}$), $NiSO_4.6H_2O$ (1.99 $mg.L^{-1}$), $FeSO_4.7H_2O$ (10.1 $mg.L^{-1}$), $FeCl_3.6H_2O$ (1.01 $mg.L^{-1}$), $CaCl_2.2H_2O$ (94.0 $mg.L^{-1}$), $CoCl_2.6H_2O$ (0.161 $mg.L^{-1}$), SeO_2 (0.139 $mg.L^{-1}$), KH_2PO_4 (170 $mg.L^{-1}$), K_2HPO_4 (43.2 $mg.L^{-1}$) and Na_2HPO_4 (66.7 $mg.L^{-1}$). It should be mentioned that concentrations of sodium bicarbonate and other salts were varied proportionally to the influent whey concentration, which varied from 4000 to 16000 $mgCOD.L^{-1}$.

The influent of reactor II consisted of synthetic wastewater, which was prepared from the following compounds, based on an organic matter concentration in the influent of 1000 $mgCOD.L^{-1}$: sucrose (77.0 $mg.L^{-1}$), amide (251 $mg.L^{-1}$), cellulose (74.8 $mg.L^{-1}$), meat extract (458 $mg.L^{-1}$), soy bean oil (112 $mg.L^{-1}$), NaCl (250 $mg.L^{-1}$), $MgCl_2.6H_2O$ (7.00 $mg.L^{-1}$), $CaCl_2.2H_2O$ (4.50 $mg.L^{-1}$), $NaHCO_3$ (440 $mg.L^{-1}$) and commercial detergent (3 $drops.L^{-1}$) for emulsification of the soy bean oil. Similar to the procedure adopted in the operation of reactor I, concentration of the compounds was varied proportionally to the organic matter concentration in the influent of reactor II, which varied from 1000 to 3440 $mgCOD.L^{-1}$.

Physical-chemical analysis and microbiological exams

The monitored variables during operation of the reactors were: organic matter concentration (as chemical oxygen demand – COD) for unfiltered (C_{TS}) and filtered samples (C_{SF}), bicarbonate alkalinity (BA), total volatile acids (TVA), total solids (TS), total volatile solids (TVS), total suspended solids (TSS) and volatile suspended solids (VSS), as well as measurement of pH and of the volume of discharged medium.

Analyses were carried out in accordance with the *Standard Methods for Examination of Water and Wastewater* (1995). Intermediate volatile acids (IVA), such as acetic, propionic, butyric, isobutyric, valeric, and isovaleric, were analyzed by gas chromatography, using a Hewlett Packard® 6890 chromatograph, Series CG System, equipped with flame ionization detector at 300°C and an innowax column (length: 30 m; internal diameter: 0.25 mm; film thickness: 0.25 μm). The injector temperature was kept at 250°C. The oven was held at 100°C for 3 min, after which it was heated at a rate of 5°C.min^{-1} to 180°C, and held at that temperature for 5 min. Hydrogen and nitrogen were used as carrier and make-up gas, respectively. Sample volume injected was 1.0 μL. Concentration of the gases in the biogas (C_{CH4} and C_{CO2}) was also analyzed by gas chromatography, using the same chromatograph equipped with thermal conductivity detector. Carrier and make-up gas were hydrogen and nitrogen, respectively. Column, injector and detector temperatures were 35, 60 and 160 ºC, respectively, and the sample volume collected was 1 mL.

At the end of each assay bioparticle samples were taken from the reactor for *(1)* microbiological analysis which was performed by means of common optical and fluorescence phase contrast microscopy with a BX41 Olympus® microscope, and *(2)* analysis of the concentration of total solids (S'_{TS}, S_{TS}) and total volatile solids (S'_{TVS}, S_{TVS}) in the reactor for estimating the concentration of biomass in the reactor, in the form of total volatile solids (S_{TVS}).

Experimental procedure

Both reactors were operated in sequencing batch with three cycles per day and eight hours per cycle. At the beginning of each cycle, each reactor was fed with a certain volume of wastewater (which varied according to the operational condition studied) for 10 minutes. Next, recirculation of the medium was initiated at a velocity of 0.19 cm.s^{-1} (Ramos *et al*., 2003) for 460 minutes. After this period, at the end of the cycle, recirculation was interrupted and a volume equal to the volume fed to the reactor was then discharged for 10 minutes.

For both reactors, the objective of the operational conditions imposed was to investigate whether process efficiency and stability would be affected when maintaining a residual volume in the reactor, at the end of each cycle, as well as to verify the intensity of that effect for different types of wastewaters and organic loading rates. Reactor I operated with an OLR of 12 gCOD.L^{-1}.d^{-1}, and at each operational condition the concentration of cheese whey in the influent increased proportionally to the decrease in the ratio of the volume fed in each cycle (Va – which was equal to the discharged volume, i.e., the treated volume per cycle) to the total volume of reaction medium in the system (Vu – which remained constant at 2.5 L in all experiments), so as to maintain a constant OLR of 12 gCOD.L^{-1}.d^{-1} in all experiments. The operational condition considered as reference (*I*) was run by feeding the reactor with 2.5 L of cheese whey at a concentration of 4000 mgCOD.L^{-1}, i.e., under this condition no residual volume was maintained and Va/Vu ratio = 1. The remaining conditions studied were: *(II)* volume fed of 1.75 L with residual volume of 0.75 L, cheese whey concentration in the influent of 5700 mgCOD.L^{-1} and Va/Vu ratio = 0.70; *(III)* volume fed of 1.25 L with residual volume of 1.25 L, cheese whey concentration in the influent of 8000 mgCOD.L^{-1} and Va/Vu ratio = 0.50; and *(IV)* volume fed of 0.63 L with residual volume of 1.87 L, cheese whey concentration in the influent of 16000 mgCOD.L^{-1}.d^{-1} and Va/Vu ratio = 0.25.

Reactor II operated under two different OLRs: 3 and 5 gCOD.L^{-1}.d^{-1}. Each OLR was maintained constant in agreement with the procedure adopted for reactor I, i.e., by increasing the concentration of synthetic wastewater in the influent proportionally to the decrease in the Va/Vu ratio. Va was the volume discharged, i.e., the volume treated per cycle and Vu the total volume of the reaction medium in the system which in the case of reactor II remained at a constant value of 1.8 L in all assays). For each OLR two conditions of Va/Vu ratio were studied: 1.00 and 0.50. For the operation at OLR of 3 gCOD.L^{-1}.d^{-1}, the reference condition was carried out by feeding the reactor with 1.8 L synthetic wastewater at a concentration of 1000 mgCOD.L^{-1}, i.e., under this condition no residual volume was maintained and Va/Vu ratio = 1.00. At the subsequent condition the reactor operated at a feed of 0.9 L synthetic wastewater, maintaining a residual volume of 0.9 L and synthetic wastewater concentration in the influent of 2000 mgCOD.L^{-1}. For the operation at OLR of 5 gCOD.L^{-1}.d^{-1}, synthetic wastewater concentrations in the influent were 1666 mgCOD.L^{-1} and 3440 mgCOD.L^{-1}, for the conditions at which Va/Vu ratio was 1.00 and 0.50, respectively. It should be mentioned that in a previous work of Bezerra *et al*. (2005), the batch operation of the system approached a continuous operation, because the applied OLR was maintained by reducing both cycle length and volume of wastewater treated per cycle. In the current study, however, OLR was maintained constant by increasing the organic matter concentration in the influent and decreasing the volume of wastewater treated per cycle.

Kinetic mathematical model and performance parameters

In both reactors, after having reached operational stability, temporal profiles were run for the main monitored variables (C_{SF}, BA, TVA, IVA, C_{CH4} and C_{CO2}). These profiles enabled a better understanding of the degradation routes along a cycle. In addition, kinetic parameters of the degradation of organic matter could be obtained by fitting a first order kinetic model to the experimental profile data of filtered organic matter concentration. Fitting was done with the aid of the Levenberg-Maquardt method (Microcal Origin 6.1©). The model is given by Equation (1), where C_{SF} is the filtered organic matter concentration inside the reactor, C_{SIO} is the organic matter concentration in the reactor at the beginning of the cycle, k_1 is the first order apparent kinetic constant, t is the time in the cycle and C_{SR} is the filtered residual organic matter concentration. It should be mentioned that the proposed kinetic model was formulated assuming a homogenous reactor, i.e., the parameter k_1 obtained by the model is actually an apparent kinetic constant, which includes not only the kinetics intrinsic to the biochemical reaction but also the mass transfer phenomena inside and outside the bioparticles.

$$C_{SF} = \left(C_{SIO} - C_{SR}\right) \cdot e^{-k_1 . t} + C_{SR} \quad (1)$$

Comparison of reactor performance under the different conditions studied was done by analyzing the values of removed organic load (ROL) by the reactor, for instance, $gCOD.L^{-1}.d^{-1}$. For batch reactors, the removed organic load for filtered (ROL_{SF}) and unfiltered samples (ROL_{TS}) in the effluent can be calculated, respectively, by Equations (2) and (3), where C_{SI} is the organic matter concentration in the influent, Va is the volume of wastewater fed in the cycle, Vu is the volume of wastewater in the reactor, n is the number of daily cycles, and C_{SF} and C_{TS} are the concentrations of organic matter in filtered and unfiltered samples of the effluent, respectively. The organic loading rate (OLR) can be defined as the amount of organic matter applied to the reactor per unit of time and per volume of medium in the reactor, for instance, $gCOD.L^{-1}.d^{-1}$, Equation (4).

$$ROL_{SF} = \frac{(C_{SI} - C_{SF}).V_a \cdot n}{V_u} \quad (2)$$

$$ROL_{TS} = \frac{(C_{SI} - C_{ST}).V_a \cdot n}{V_u} \quad (3)$$

$$OLR = \frac{C_{SI} \cdot V_a \cdot n}{V_u} \quad (4)$$

Considering the main objective of this work, i.e., investigation of the effect of the ratio of the volume of wastewater fed per cycle to the volume of reaction medium in the reactor (Va/Vu) on reactor performance, it became important to define the specific feed volume (D), since this parameter is directly related to the Va/Vu ratio. The specific feed volume has certain analogy to the "specific feed rate" (Q/V) of continuous reactors. For batch reactors, the specific feed volume is calculated through Equation (5), and is defined as the ratio of the volume of wastewater fed per day and the volume of reaction medium in the reactor.

$$D = \frac{V_a \cdot n}{V_u} \quad (5)$$

RESULTS AND DISCUSSION

Tables 1 and 2 contain the average values of the monitored variables in the influent and effluent of reactor I, for the four specific feed volumes studied. Figure 2 shows values of removed organic load, for reactor I, of filtered and unfiltered effluent samples as a function of specific feed volume.

Table 2 shows that maintaining different residual volumes in the reactor, at the end of each cycle, did not significantly alter the organic matter concentrations for filtered samples in the effluent, which remained around 904, 952, 883, and 890 $mgCOD.L^{-1}$, for the assays in which the specific feed volumes were 3.00, 2.10, 1.50 and 0.75 d^{-1}, which corresponded to Va/Vu ratios of 1.00, 0.70, 0.50 and 0.25, respectively. For unfiltered samples in the effluent, operation with 70 % volume renewal (D = 2.10 d^{-1}) presented the lowest value of organic matter concentration in relation to the remaining conditions: 1151 $mgCOD.L^{-1}$, against 1352, 1533 and 1592 $mgCOD.L^{-1}$, for volume renewals of 100 % (D = 3.00 d^{-1}), 50 % (D = 1.50 d^{-1}) and 25 % (D = 0.75 d^{-1}), respectively. Hence, in terms of quality of unfiltered and, primarily, of filtered effluent samples, maintaining different residual volumes in the reactor did not significantly affect effluent characteristics.

Despite the fact that the different operational conditions did not cause significant alterations in the organic matter concentration in the effluent, values of removed organic load (Table 2 and Figure 2) were seen to increase with increase in the residual volume maintained in the reactor at the end of each cycle (7.97, 9.62, 9.87 and 10.94 $gCOD.L^{-1}.d^{-1}$, for unfiltered effluent samples; and 9.32, 10.04, 10.85 and 11.47 $gCOD.L^{-1}.d^{-1}$, for filtered effluent samples; for the conditions in which the specific feed volumes were 3.00, 2.10, 1.50 and 0.75 d^{-1}, respectively), i.e., despite the fact that reduction in the specific feed volume did not significantly affect the quality of the effluent (Table 2), in quantitative terms this reduction resulted in an increase in the amount of organic matter removed by the reactor (Figure 2), thus indicating improved reactor performance under the conditions when initial influent dilution was highest. The average values of solids concentration in the influent and effluent of the reactor showed that no solids loss occurred under any of the conditions. The first order apparent kinetic constant showed a slight increase with decreasing renewed volume per cycle: 0.54 e 0.66 h^{-1}, when renewed volumes were 100 and 70 %, respectively, corroborating the improved results of removed organic load under the conditions of lowest renewed volume.

Analysis of Table 1 shows that bicarbonate alkalinity in the influent increased as the specific feed volume decreased. This was expected, because the organic matter concentration in the influent was higher at lower Va/Vu values and since the supplementation of sodium bicarbonate to the influent was always maintained at 0.50 $gNaHCO_3/gCOD_{fed}$, i.e., since supplementation of bicarbonate alkalinity in the influent was proportional to the organic matter concentration, increase of alkalinity in the influent was likely to occur at decreasing specific feed volume. However, since the OLR was maintained constant at 12 $gCOD.L^{-1}.d^{-1}$ during the four conditions studied, it can be concluded that the amount of bicarbonate alkalinity supplied per day and per reactor volume was also maintained constant. However, Table 2 shows that even with the supply of alkalinity to the reactor being maintained constant, alkalinity in the effluent increased as the specific feed volume decreased: average of 1294, 1385, 1906 and 2836 $mgCaCO_3.L^{-1}$, under the conditions in which the specific feed volumes were maintained at 3.00, 2.10, 1.50 and 0.75 d^{-1}, respectively, indicating increased capacity to produce alkalinity at lower specific feed volumes. This result might be related to the operational characteristics of the reactor, which allowed maintaining a larger amount of bicarbonate alkalinity that remained from the previous cycle in the residual volume of the reactor at lower specific feed volumes. This alkalinity contributes to a higher alkalinity production capacity in the subsequent cycle and, therefore, to an improved reactor stability and operational safety. With regard to the concentration of total volatile acids in the effluent, alteration in the specific feed volume did not significantly affect the average values of this variable. TVA concentrations remained around 512, 568, 583 and 550 $mgHAc.L^{-1}$ for specific feed volumes of 3.00, 2.10, 1.50 and 0.75 d^{-1}, respectively. However, the comparison of the average TVA values, presented in Tables 1 and 2, showed that the ratio of the acid concentration in the effluent to that in the influent of the reactor was seen to be lower at lower specific feed volumes. This is an important observation, because the improved capacity to neutralize acids, verified at lower specific feed volume conditions, might reside exactly in the improved capacity to produce alkalinity observed under those conditions; alkalinity that might have contributed to neutralization of the acids and to increased process stability.

Variable $^{(e)}$	**D (d^{-1})**			
	3.00 $^{(a)}$	**2.10** $^{(b)}$	**1.50** $^{(c)}$	**0.75** $^{(d)}$
C_{SI} (mgCOD.L^{-1})	4010 ± 71 $^{(10)}$	5732 ± 303 $^{(8)}$	8116 ± 100 $^{(6)}$	16060 ± 200 $^{(4)}$
TVA (mgHAc.L^{-1})	204 ± 15 $^{(10)}$	273 ± 12 $^{(7)}$	440 ± 14 $^{(3)}$	812 ± 32 $^{(4)}$
BA (mgCaCO$_3$.L^{-1})	1161 ± 55 $^{(10)}$	1608 ± 75 $^{(7)}$	2271 ± 52 $^{(3)}$	4463 ± 158 $^{(4)}$
pH	7.8 ± 0.1 $^{(10)}$	7.8 ± 0.1 $^{(7)}$	7.6 ± 0.1 $^{(3)}$	7.6 ± 0.2 $^{(4)}$
TS (mg.L^{-1})	5539 ± 101 $^{(10)}$	7587 ± 549 $^{(3)}$	9890 $^{(1)}$	21667 ± 1956 $^{(2)}$
TVS (mg.L^{-1})	3728 ± 208 $^{(10)}$	5085 ± 375 $^{(3)}$	6526 $^{(1)}$	12952 ± 249 $^{(2)}$
TSS (mg.L^{-1})	177 ± 29 $^{(10)}$	205 ± 34 $^{(3)}$	316 $^{(1)}$	408 ± 51 $^{(2)}$
VSS (mg.L^{-1})	135 ± 26 $^{(10)}$	142 ± 43 $^{(3)}$	204 $^{(1)}$	230 ± 48 $^{(2)}$

(a)/(b)/(c)/(d) *Duration of the condition (days): 16/14/8/7.*

(a)/(b)/(c)/(d) *Corresponding Va/Vu ratio: 1.00/0.70/0.50/0.25.*

(e) *Number in brackets refers to the number of samples used for averaging.*

Table 2 – Average values of the monitored variables in the effluent of reactor I.

Variable $^{(a)}$	**D (d^{-1})** $^{(b)}$			
	3.00	**2.10**	**1.50**	**0.75**
C_{TS} (mgCOD.L^{-1})	1352 ± 87 $^{(10)}$	1151 ± 169 $^{(8)}$	1533 ± 150 $^{(6)}$	1592 ± 150 $^{(4)}$
ε_{TS} (%)	66 ± 2 $^{(10)}$	80 ± 2 $^{(8)}$	81 ± 2 $^{(6)}$	90 ± 1 $^{(4)}$
C_{SF} (mgCOD.L^{-1})	904 ± 50 $^{(10)}$	952 ± 136 $^{(8)}$	883 ± 91 $^{(6)}$	890 ± 82 $^{(4)}$
ε_{SF} (%)	78 ± 1 $^{(10)}$	83 ± 2 $^{(8)}$	89 ± 1 $^{(6)}$	95 ± 1 $^{(4)}$
TVA (mgHAc.L^{-1})	512 ± 31 $^{(10)}$	568 ± 86 $^{(7)}$	583 ± 60 $^{(7)}$	550 ± 46 $^{(4)}$
BA (mgCaCO$_3$.L^{-1})	1294 ± 76 $^{(10)}$	1385 ± 65 $^{(7)}$	1906 ± 384 $^{(7)}$	2836 ± 268 $^{(4)}$
pH	7.3 ± 0.1 $^{(10)}$	7.3 ± 0.2 $^{(7)}$	7.4 ± 0.2 $^{(7)}$	7.8 ± 0.2 $^{(4)}$
ROL_{TS} (gCOD.L^{-1}.d^{-1})	7.97 $^{(10)}$	9.62 $^{(8)}$	9.87 $^{(6)}$	10.94 $^{(4)}$
ROL_{SF} (gCOD.L^{-1}.d^{-1})	9.32 $^{(10)}$	10.04 $^{(8)}$	10.85 $^{(6)}$	11.47 $^{(4)}$
k_1 (h^{-1})	0.54 ± 0.05	0.66 ± 0.08	-	-
TS (mg.L^{-1})	2791 ± 76 $^{(10)}$	3286 ± 280 $^{(2)}$	3566 $^{(1)}$	5407 ± 912 $^{(2)}$
TVS (mg.L^{-1})	1086 ± 76 $^{(10)}$	1053 ± 7 $^{(2)}$	1338 $^{(1)}$	1359 ± 191 $^{(2)}$
TSS (mg.L^{-1})	217 ± 36 $^{(10)}$	214 ± 25 $^{(2)}$	246 $^{(1)}$	220 ± 40 $^{(2)}$
VSS (mg.L^{-1})	175 ± 45 $^{(10)}$	135 ± 38 $^{(2)}$	176 $^{(1)}$	142 ± 8 $^{(2)}$

(a) *Number in brackets refers to the number of samples used for averaging.*

(b) *Biomass in the reactor (average value for the four operational conditions):*
S'_{TS} = 1659 ± 200 mg.g foam^{-1}; S'_{TVS} = 1467 ± 142 mg.g foam^{-1};
S_{TS} = 46 ± 5 g.L reaction medium^{-1}; S_{TVS} = 41 ± 5 g.L reaction medium^{-1}; S_{TVS}/S_{TS} = 0.88 ± 0.02.

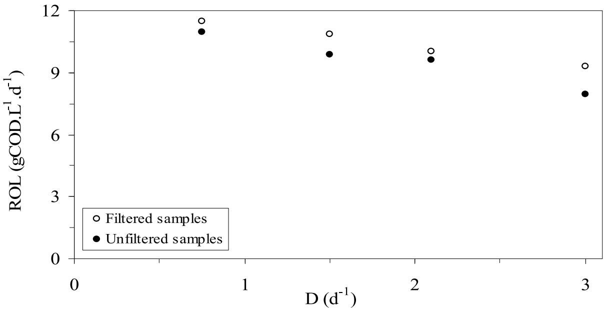

Figure 2 – Removed organic load by reactor I as a function of the specific feed volume.

Figure 3 contains the profiles run under the conditions at which reactor I operated with renewal of 100 and 70 % of the reaction medium volume (specific feed volume of 3.00 and 2.10 d^{-1}, respectively), at an OLR of 12 gCOD.L^{-1}.d^{-1}. Results of the profiles showed that these followed the same trend, regardless of the volume discharged per cycle. For the condition at which reactor I operated with renewal of 100 % of its volume (D = 3.00 d^{-1}), the initial concentration (time zero) of filtered organic matter in the reactor was 3644 mgCOD.L^{-1}, i.e., practically equal to that observed in the profile of the condition at which the reactor operated with renewal of 70 % of its volume (D = 2.10 d^{-1}), which was 3646 mgCOD.L^{-1}. This happened because at the latter condition, despite having maintained the organic matter concentration in the influent at a higher value (5700 mgCOD.L^{-1}) than that imposed at the condition of complete volume renewal at each cycle (4000 mgCOD.L^{-1}), the residual volume maintained in the reactor (30 % of the volume of reaction medium) caused an initial dilution of the influent and the initial concentration of filtered organic matter in the reactor approached that observed in the profile of the condition at which reactor discharge was complete. Bicarbonate alkalinity profiles presented an initial value of around 1772 mgCaCO$_3$.L^{-1} for the operational condition at which renewal was 70 % of the medium at each cycle (D = 2.10 d^{-1}). The lowest value of around 1310 mgCaCO$_3$.L^{-1} was observed for the previous condition, at which no residual volume was maintained. This result confirms the assumptions made that process stability would be favored by maintaining remnant bicarbonate alkalinity in the residual volume of the reactor during partial discharge.

Analysis of the profiles also allowed verifying that, regardless of specific feed volume adopted, concentration of total volatile acids at the end of the cycle was higher than that at the beginning of the cycle. Hence, at the applied OLR, cycle length was insufficient for higher consumption of the volatile acids formed, which can be confirmed by the absence of a stability plateau in the organic matter concentration profiles. Despite this fact, acids did not tend to accumulate over time, because the system became stable; effluent pH remained close to neutral and alkalinity supplied to the influent was sufficient to neutralize the formed acids and maintain reactor stability. Intermediate volatile acids profiles showed that the amount of each identified acid practically did not change with changing conditions. The main acids identified, i.e., those at higher concentrations, were acetic and propionic acid.

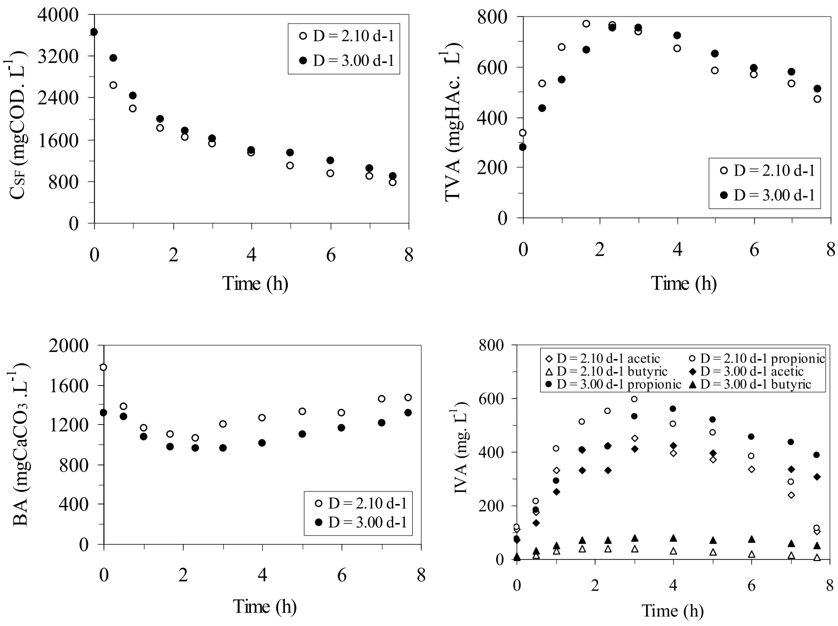

Figure 3 – Profiles of the main monitored variables in reactor I at an OLR of 12 gCOD.L^{-1}.d^{-1}.

Tables 3 and 4 contain, respectively, the average values of the monitored variables in the influent and effluent of reactor II, for the two specific feed volumes studied. Total operation time of reactor II was 77 days: 36 and 15 days for the operation with OLR of 3 gCOD.L^{-1}.d^{-1}, and 18 and 8 days for the operation with OLR of 5 gCOD.L^{-1}.d^{-1}, at specific feed volumes of 3.00 and 1.50 d^{-1}, respectively. Figure 4 shows values of removed organic load, for reactor II, of filtered and unfiltered effluent samples as a function of specific feed volume.

Analysis of Table 4 shows that at OLR of 3 gCOD.L^{-1}.d^{-1}, reduction in specific feed volume did not significantly affect quality of the effluent (for the assays with specific feed volume of 3.00 and 1.50 d^{-1}, the average organic matter concentration, for unfiltered effluent samples were 193 and 164 mgCOD.L^{-1}.d^{-1}, and for filtered effluent samples, 154 and 131 mgCOD.L^{-1}.d^{-1}, respectively) nor the amount of organic matter removed by the reactor (at specific feed volumes of 3.00 and 1.50 d^{-1}, the removed organic load values for unfiltered effluent samples were 2.62 and 2.78 gCOD.L^{-1}.d^{-1}, and for filtered effluent samples, 2.74 and 2.83 gCOD.L^{-1}.d^{-1}, respectively). Total volatile acids concentration in the effluent remained around 29 and 36 mgHAc.L^{-1} at specific feed volumes of 3.00 and 1.50 d^{-1}, respectively.

In terms of effluent quality, when the OLR was 5 gCOD.L^{-1}.d^{-1}, reactor II presented different behavior at changing specific feed volume. The difference was more significant for the main monitored variables in the effluent. At this OLR, the best effluent quality was observed for the assay with total volume discharge. Quality of the reactor effluent dropped when operation took place with 50 % volume renewal in each cycle (D = 1.50 d^{-1}). For the operational conditions at which volume renewal was 100 and 50 %, average organic matter concentrations for unfiltered samples in the effluent were 224 and 362 mgCOD.L^{-1}, and for filtered samples in the effluent, 189 and 288 mgCOD.L^{-1}, respectively. Despite this drop, reactor stability was maintained and pH of the medium remained close to neutrality during the entire period, i.e., it remained always within the range of pH favorable to the development of methane-forming microorganisms. Average TVA concentrations were 42 and 74 mgHAc.L^{-1}, for the assays at which the reactor operated with total and partial discharge, respectively, corroborating the best results, in terms of effluent quality at the condition of complete reactor discharge. In terms of removed organic load (Figure 4), operation at OLR of 5 gCOD.L^{-1}.d^{-1} showed that, analogous to operation at 3 gCOD.L^{-1}.d^{-1}, varying the specific feed volume did not significantly affect reactor performance (4.36 and 4.42 gCOD.L^{-1}.d^{-1}, for unfiltered effluent samples, and 4.47 and 4.53 gCOD.L^{-1}.d^{-1}, for filtered effluent samples, at specific feed volume of 3.00 and 1.50 d^{-1}). Considering the values of the apparent kinetic constant and the

Table 3 – Average values of the monitored variables in the influent of reactor II.

Variable (e)	**3 gCOD.L^{-1}.d^{-1}**		**5 gCOD.L^{-1}.d^{-1}**	
	D = 3.00 d^{-1} (a)	**D = 1.50 d^{-1} (b)**	**D = 3.00 d^{-1} (c)**	**D = 1.50 d^{-1} (d)**
C_{SI} (mgCOD.L^{-1})	1066 ± 76 (7)	2020 ± 98 (6)	1679 ± 212 (8)	3309 ± 232 (4)
TVA (mgHAc.L^{-1})	51 ± 11 (8)	173 ± 1 (2)	79 ± 14 (4)	219 (1)
BA (mgCaCO$_3$.L^{-1})	316 ± 13 (8)	499 ± 11 (2)	509 ± 39 (4)	706 (1)
pH	9.0 ± 0.2 (8)	8.9 ± 0.1 (2)	9.0 ± 0.1 (4)	9.1 (1)
TS (mg.L^{-1})	2277 ± 293 (3)	3174 ± 416 (2)	2769 ± 313 (3)	4046 (1)
TVS (mg.L^{-1})	1294 ± 284 (3)	1678 ± 105 (2)	1381± 250 (3)	2484 (1)
TSS (mg.L^{-1})	362 ± 300 (3)	89 ± 16 (2)	124± 72 (3)	102 (1)
VSS (mg.L^{-1})	347 ± 291 (3)	58 ± 6 (2)	99 ± 79 (3)	76 (1)

(a)/(b)/(c)/(d) *Duration of the condition (days): 36/15/18/8.*

(a)/(b)/(c)/(d) *Corresponding Va/Vu ratio: 1.00/0.50/1.00/0.50.*

(e) *Number in brackets refers to the number of samples used for averaging.*

Table 4 – Average values of the monitored variables in the effluent of reactor II.

Variable $^{(a)}$	3 gCOD.L^{-1}.d^{-1} $^{(b)}$		5 gCOD.L^{-1}.d^{-1} $^{(b)}$	
	D = 3.00 d^{-1}	**D = 1.50 d^{-1}**	**D = 3.00 d^{-1}**	**D = 1.50 d^{-1}**
C_{TS} (mgCOD.L^{-1})	193 ± 51 $^{(7)}$	164 ± 34 $^{(6)}$	224 ± 57 $^{(8)}$	362 ± 70 $^{(4)}$
ε_{TS} (%)	82 ± 4 $^{(7)}$	92 ± 2 $^{(6)}$	87 ± 3 $^{(8)}$	89 ± 3 $^{(4)}$
C_{SF} (mgCOD.L^{-1})	154 ± 31 $^{(7)}$	131 ± 47 $^{(6)}$	189 ± 52 $^{(8)}$	288 ± 80 $^{(4)}$
ε_{SF} (%)	86 ± 3 $^{(7)}$	94 ± 2 $^{(6)}$	89 ± 3 $^{(8)}$	91 ± 3 $^{(4)}$
TVA (mgHAc.L^{-1})	29 ± 11 $^{(9)}$	36 ± 20 $^{(4)}$	42 ± 18 $^{(7)}$	74 ± 28 $^{(3)}$
BA (mgCaCO$_3$.L^{-1})	508 ± 20 $^{(9)}$	992 ± 34 $^{(4)}$	811 ± 51 $^{(7)}$	1094 ± 44 $^{(3)}$
pH	7.4 ± 0.3 $^{(9)}$	7.6 ± 0.2 $^{(4)}$	7.3 ± 0.2 $^{(7)}$	7.6 ± 0.1 $^{(3)}$
ROL_{TS} (gCOD.L^{-1}.d^{-1})	2.62 $^{(7)}$	2.78 $^{(6)}$	4.36 $^{(8)}$	4.42 $^{(4)}$
ROL_{SF} (gCOD.L^{-1}.d^{-1})	2.74 $^{(7)}$	2.83 $^{(6)}$	4.47 $^{(8)}$	4.53 $^{(4)}$
k_1 (h^{-1})	0.91 ± 0.11 $^{(1)}$	0.67 ± 0.05 $^{(1)}$	0.58 ± 0.14 $^{(1)}$	0.53 ± 0.06 $^{(1)}$
TS (mg.L^{-1})	1319 ± 164 $^{(3)}$	2204 ± 440 $^{(3)}$	1915 ± 107 $^{(3)}$	2308 $^{(1)}$
TVS (mg.L^{-1})	463 ± 37 $^{(3)}$	602 ± 4 $^{(3)}$	627 ± 44 $^{(3)}$	744 $^{(1)}$
TSS (mg.L^{-1})	70 ± 17 $^{(3)}$	83 ± 31 $^{(3)}$	81 ± 39 $^{(3)}$	88 $^{(1)}$
VSS (mg.L^{-1})	8 ± 8 $^{(3)}$	65 ± 18 $^{(3)}$	66 ± 10 $^{(3)}$	72 $^{(1)}$

(a) *Number in brackets refers to the number of samples used for averaging.*

(b) *Biomass in the reactor (average value for the four operational conditions):*
S'_{TS} *= 2100 ± 220 mg.g foam*$^{-1}$*;* S'_{TVS} *= 1800 ± 169 mg.g foam*$^{-1}$*;*
S_{TS} *= 43 ± 4 g.L reaction medium*$^{-1}$*;* S_{TVS} *= 37 ± 3 g.L reaction medium*$^{-1}$*;* S_{TVS}/S_{TS} *= 0.86 ± 0.02.*

standard deviation obtained, it can be stated that the renewed volume did not affect this parameter, which was 0.58 and 0.53 h^{-1}, for the specific feed volumes of 3.00 and 1.50 d^{-1}, respectively.

Figures 5 and 6 depict, for the two specific feed volumes, the profiles of the main monitored variables run during operation of reactor II under OLR of 3 and 5 gCOD.L^{-1}.d^{-1}, respectively. For all conditions, the profiles showed maintenance of the degradation routes, with consumption of organic matter and generation of methane during the entire cycle. Methane is one of the end products of the anaerobic digestion process, which proves that the process was complete and that the reactor did not retain organic matter and degraded the substrate through anaerobic routes. TVA profiles revealed, as observed in reactor I, acid formation and consumption at the beginning and at the end of the cycle, respectively. However, in contrast with the behavior observed during cheese whey treatment, TVA profiles showed lower values of this variable at the end of the cycle in relation to that observed at the beginning of the cycle, for the two OLRs applied. This result can be explained not only by the intrinsic characteristics of each one of the substrates used, i.e., by the lower biodegradability of synthetic wastewater in relation to cheese whey, but also by the operational characteristic adopted, i.e., by the lower OLR applied during operation of reactor II, which enabled improved control of acids formation at the beginning of the cycle, preventing attainment of high concentrations and, consequently, making cycle length sufficient for a higher consumption. This is confirmed by the stability plateau at the last hour of the cycle in the organic matter concentration profiles in reactor II.

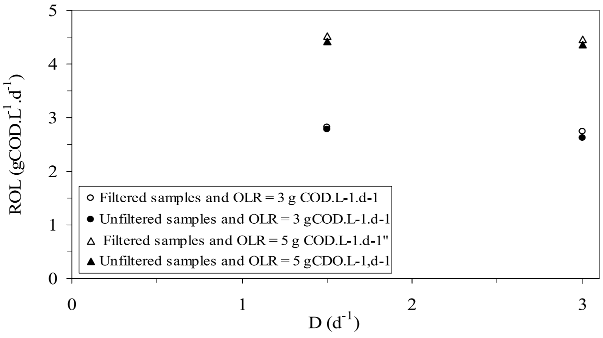

Figure 4 – Removed organic load by reactor II as a function of the specific feed volume and organic loading rate.

Regarding solids analyses relative to the immobilized biomass, for both reactors immobilization seemed to be effective and no biomass was lost by the support, i.e., the values of total solids (S'_{TS}) and total volatile solids (S'_{TVS}) per gram dry foam suffered little variation during the imposed operational conditions, remaining, respectively, in reactor I, around 1659 and 1467 mg.g foam^{-1}; and in reactor II, around 2100 and 1800 mg.g foam^{-1}. Total volatile solids concentration (S_{TVS}) in reactor I and II were close: 41 and 37 g.L reaction medium^{-1}, respectively, enabling a more reliable comparison of the results of the reactors.

For both reactors, microbiological analyses showed the existence of cells similar to bacilli and vibriones inside the support, as well as the presence of *Methanosaeta*-like and *Methanosarcina*-like morphologies, with equilibrium in the distribution of these two genuses.

CONCLUSIONS

In terms of effluent quality, the reactor used for cheese whey treatment did not present large variations in organic matter concentration for unfiltered and especially for filtered samples in the effluent with varying specific feed volume. Despite the fact that reduction in the specific feed volume did not significantly affect the quality of the effluent, in quantitative terms, this reduction resulted in an increase in the amount of organic matter removed by the reactor, which is corroborated by the increase in the values of removed organic load for the conditions at which the reactor was operated with the lowest renewed volumes.

Regarding the reactor used to treat synthetic wastewater, at OLR of 3 gCOD.L^{-1}.d^{-1} the reduction in the specific feed volume did not significantly affect neither the effluent quality nor the amount of organic matter removed by the reactor, which is confirmed by the similar values of organic matter concentration in the effluent and removed organic load, respectively, for both renewed volume operational conditions. As verified at OLR of 3 gCOD.L^{-1}.d^{-1}, the amount of organic matter removed by the reactor at operation with OLR of 5 gCOD.L^{-1}.d^{-1} showed to be independent of the specific feed volume. That is, for the reactor treating syn-

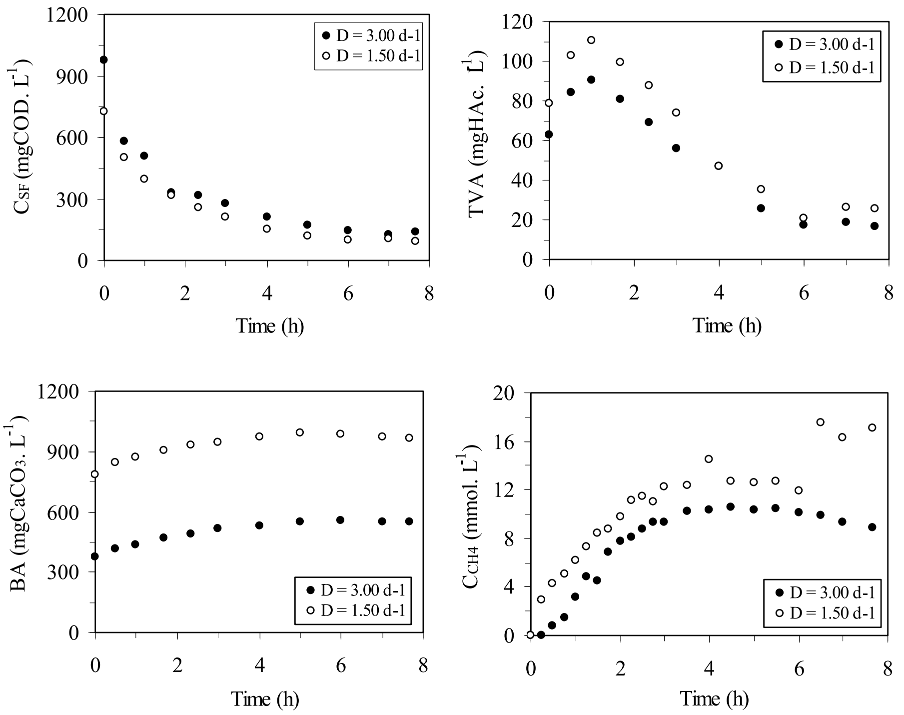

Figure 5 – Profiles of the main monitored variables in reactor II at an OLR of 3 gCOD.L^{-1}.d^{-1}.

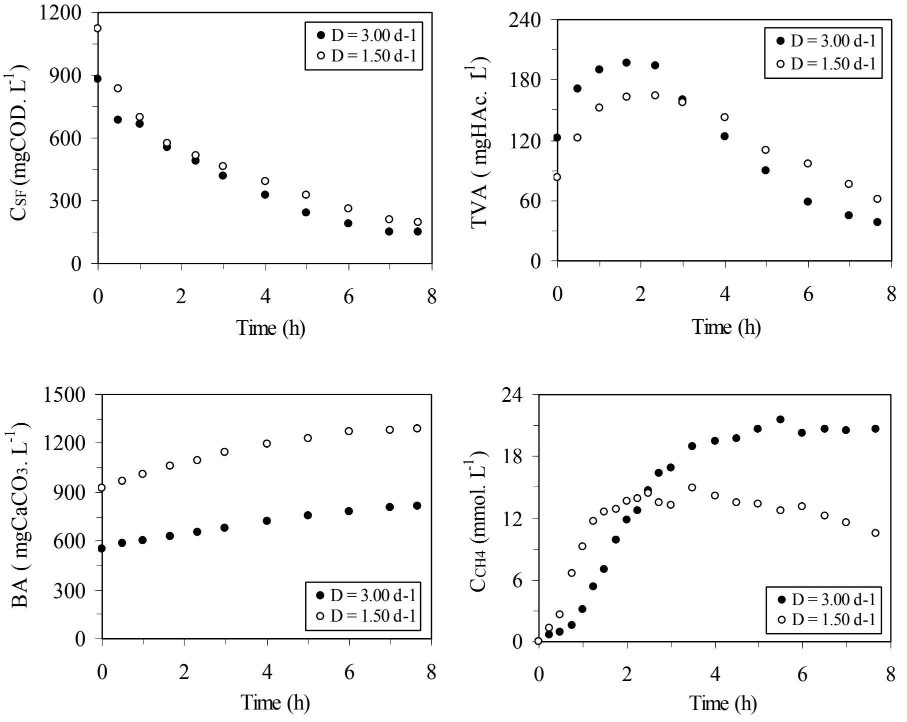

Figure 6 – Profiles of the main monitored variables in reactor II at an OLR of 5 gCOD.L^{-1}.d^{-1}.

thetic wastewater, the reduction in the specific feed volume did not affect the removed organic load values, regardless of the organic loading rate applied. However, in terms of effluent quality, operation with complete discharge of the medium at each cycle, at OLR of 5 gCOD.L^{-1}.d^{-1}, resulted in lower organic matter concentrations in the effluent, in relation to operation with partial discharge.

In general, the results showed process stability under all investigated conditions, evidence of the flexibility and potential application of this reactor configuration to the treatment of different types of wastewater.

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NOMENCLATURE

Symbols:
OLR – organic loading rate, gCOD.L^{-1}.d^{-1}
C_{TS} – unfiltered organic matter concentration in the effluent, mgCOD.L^{-1}
C_{SF} – filtered organic matter concentration in the effluent, mgCOD.L^{-1}
BA – bicarbonate alkalinity, mgCaCO$_3$.L^{-1}
TVA – concentration of total volatile acids, mgHAc.L^{-1}
TS – concentration of total solids, mg.L^{-1}
TVS – concentration of total volatile solids, mg.L^{-1}
TSS – concentration of total suspended solids, mg.L^{-1}
VSS – concentration of volatile suspended solids, mg.L^{-1}
IVA – concentration of intermediate volatile acids, mg.L^{-1}
C_{CH4} – concentration of methane in the biogas, mMol.L^{-1}
C_{CO2} – concentration of carbon gas in the biogas, mMol.L^{-1}
C_{SI} – unfiltered organic matter concentration in the influent, mgCOD.L^{-1}
C_S – organic matter concentration in the reactor, mgCOD.L^{-1}
Va – volume fed, discharged, treated or renewed per cycle, L
Vu – volume of reaction medium in the reactor, L
Va/Vu – ratio of the volume fed to the volume of reaction medium in the reactor
Q – feed flow rate of continuous reactors, L.d^{-1}
D – specific feed volume, d^{-1}
n – number of daily cycles
S'_{TVS} – concentration of total volatile solids relative to the immobilized biomass on the support, mgTVS.g foam^{-1}
S_{TVS} – concentration of total volatile solids relative to the immobilized biomass in the reactor, gTVS.L reaction medium^{-1}
S'_{TS} – concentration of total solids relative to the immobilized biomass on the support, mgTS.g foam^{-1}
S_{TS} – concentration of total solids relative to the immobilized biomass in the reactor, gTS.L reaction medium^{-1}
C_{SR} – residual concentration of filtered organic matter, mgCOD.L^{-1}
C_{SIO} – concentration of filtered organic matter in the reactor at the beginning of the cycle, mgCOD.L^{-1}
k_1 – first order apparent kinetic constant, h^{-1}
t – time in the cycle, h
ROL – removed organic load, gCOD.L^{-1}.d^{-1}
ROL_{SF} – removed organic load from filtered samples in the effluent, gCOD.L^{-1}.d^{-1}
ROL_{TS} – removed organic load from unfiltered samples in the effluent, gCOD.L^{-1}.d^{-1}
t_c – cycle time, h
S_{TVS}/S_{TS} – ratio of the concentration of total volatile solids to total solids relative to the immobilized biomass
ε – efficiency of organic matter removal, %
Acronyms:
AnSBBR – anaerobic sequencing batch biofilm reactor
ASBR – anaerobic sequencing batch reactor
UASB – upflow anaerobic sludge blanket
COD – chemical oxygen demand

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