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Influence of total solid and inoculum contents on performance of anaerobic reactors treating food waste

T. Forster-Carneiro, M. Pérez*, L.I. Romero

Department of Chemical Engineering, Food Technology and Environmental Technologies, Faculty of Sea Sciences and Environmental Sciences, University of Cadiz, Campus Rio San Pedro s/n, 11510 Puerto Real, Cádiz, Spain

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Abstract

The aim of this paper was to analyze the biomethanization process of food waste (FW) from a university campus restaurant in six reactors with three different total solid percentages (20%, 25% and 30% TS) and two different inoculum percentages (20–30% of mesophilic sludge). The experimental procedure was programmed to select the initial performance parameters (total solid and inoculum contents) in a lab-reactor with V: 1100 mL and, later, to validate the optimal parameters in a lab-scale batch reactor with V: 5000 mL. The best performance for food waste biodegradation and methane generation was the reactor with 20% of total solid and 30% of inoculum: give rise to an acclimation stage with acidogenic/acetogenic activity between 20 and 60 days and methane yield of 0.49 L CH4/g VS. Also, lab-scale batch reactor (V: 5000 mL) exhibit the classical waste decomposition pattern and the process was completed with high values of methane yield (0.22 L CH_4/g VS). Finally, a protocol was proposed to enhance the start-up phase for dry thermophilic anaerobic digestion of food waste.

Keywords: Food waste; Thermophilic digestion; Dry conditions; Inoculum source; Methane

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1. Introduction

Questions related to the final disposal and treatment of municipal solid waste (MSW) constitutes one of the most serious problems of contemporary societies. The volume of waste has increased very quickly (approximately 24 millions of metric ton of MSW has been generated in Spain last year, with 40–45% of organic fraction (OFMSW) (INE, 2006). The need for processes in the field of conservation of resources has become more than clear in recent years.

Biological treatment already demonstrated that is one of the most advantageous methods for maximizing recycle and recovering its components. Anaerobic digestion of sorted organic fraction of municipal solid wastes, especially food wastes, is the utmost attractive alternative and the most cost-effective technology (Bouallagui et al., 2004; Chynoweth et al., 2002; Mata-Alvarez et al., 1992; Rao and Singh, 2004; Forster-Carneiro et al., 2004,2006; Bolzonella et al., 2003; Bonzonella et al., 2005). Generally, the overall anaerobic organic solid digestion stages can be roughly classified into hydrolysis, acidogenesis, acetogenesis and methanogenesis (Chynoweth et al., 2002), each metabolic stage is functioned by a series of microorganisms. From these four stages, hydrolysis, which includes various enzyme functions involving carbon, nitrogen and phosphorus cycles, is the most rates limiting stage (Christ et al., 2000).

One of the most important factors affecting anaerobic digestion of organic solid waste is temperature (Ahring, 1992). Generally, anaerobic digestion process is operated under mesophilic or thermophilic condition, in which thermophilic digestion is reported to be the more efficient method (De Baere, 2000; De la Rubia et al., 2005). In

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* Corresponding author. Tel.: +34 956016158; fax: +34 956016411.
E-mail address: montserrat.perez@uca.es (M. Pérez).

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addition, it is usually difficult to maintain an appropriate circumstance to each microorganism and the problems caused by imbalance of production and consumption of intermediary products often occur in practical anaerobic process, especially during the start-up period. However, the anaerobic digestion process can restore its efficiency from imbalance circumstances, such as the lower pH condition owning to the accumulation of volatile fatty acids (VFAs) and the consumption of alkalinity.

Conventional anaerobic digesters require feed material with total solids content below 10%. Modern systems can deal with >20% total solids content in the feed. Anaerobic digestion in semi-dry (Pavan et al., 1994) (total solids content of 10–20%) and dry conditions is considered capable of producing an inert bio-solid product with higher methane productivity (Mata-Alvarez et al., 2000; De Baere, 2000). Compared with wet anaerobic digestion, dry anaerobic digestion has several advantages, such as compact digester with high organic loading rate and energetically effective performance (Pavan et al., 2000). This process also results in a lower production of leachate and easier handle of digested residues that can be further treated by composting process or be used as fertilizer (Ten Brummeler, 2000).

Also, it is crucial the selection of waste/inoculum ratio as well as the assessment of anaerobic biodegradability of solid wastes (Lopes et al., 2004). The percentage of inoculation for acidogenic fermentation of organic urban wastes is approximately 30% weight/weight (w/w) (Sans et al., 1995). In case of the anaerobic biodegradability of solid waste, the use of a highly active anaerobic inoculum or animal inoculum waste will reduce significantly the experimental time, or reduce the amount of inoculum required in full scale batch digesters, and consequently, the corresponding digester volume (Obaja et al., 2003). In dry-thermophilic digestion, the inoculum source and the total solid percentage selected are responsible to accomplish rapid onset of a balanced microbial population. Also, the start up phase is considered the most critical step in the operation of anaerobic digesters.

So far, few reports can be found on the study of dry anaerobic digestion of food wastes, and the explanation of solid wastes anaerobic digestion performance in the start-up period from the point of view of the total solids content and proportion of the inoculum used is not extensively investigated yet.

Hence, the aims of this study were to investigate the start-up performance of dry anaerobic digestion of food waste and sewage sludge under thermophilic conditions in six completely mixed one phase anaerobic digester in a lab-scale experimental process. Hence, the experimental procedure is programming to study: (a) the influence of initial total solid contents in the digester, (b) the influence of the inoculum percentages in the treatment process of fermentable food waste and (c) to propose a protocol to enhance the start-up phase for dry-thermophilic anaerobic digestion of food waste.

2. Methods

2.1. Reactors used

2.1.1. Batch reactors

The system was conformed by six reactors. The assays were carried out in batch reactors with an internal diameter of 10.45 cm and a total height of 32.15 cm. The total volume capacity was 1.1 L (laboratory scale) with net volume of 0.7 L. Each reactor had independent agitation system and electric control. The main axis contained 14 horizontal and cylindrical crosses willing to different heights, and it rotated in alternate senses by means of a cylindrical temporize, capable to maintain uniform moisture content and to redistribute soluble substrate and bacteria. The operational temperature was 55 °C, controlled and monitored by means of thermostatic bath model SELECT CORP.

The conditions selected were: dry anaerobic digestion (with 20%, 25% and 30% TS), and two different proportions between FW/inoculum loaded in the reactors (80/20 and 70/30) at single phase thermophilic (55 °C) condition.

2.1.2. Lab-scale stirred tank reactor (STR20-30)

The assays were carried on batch laboratory scale reactor with total capacity of 5.0 L (STR20-30). The cover of each reactor incorporated three separate ports for different functions: pH control; mechanical agitation system; measurement of the biogas composition and production (use of the Tedlar bag, 40 L); a temperature control by means of recirculation of the internal liquid; taking liquid samples. This configuration allowed the systems to operate under high-solids conditions without any hindrance to the leachate circulation and without the need for maintenance of mechanical devices. It is a continuous flow reactor based on the fundamental of attainment a good contact between the biomass and the effluent for the development of a balanced process and with some appropriate yields. The experiments were performed under thermophilic conditions (55 °C) and dry (20% total solid) conditions, with 30% of inoculation.

2.2. Characteristic of food waste and inoculum

The study is programmed to evaluate the thermophilic anaerobic digestion of FW at three different initial concentrations of total solids in the process, 20% TS, 25% TS and 30% TS and two different initial inoculum percentages (20% and 30%).

Table 1 resumes the characteristics and composition of each reactor: (R20-20) 20%TS_20%SLUDGE; (R20-30) 20%TS_30%SLUDGE; (R25-20) 25%TS_20%SLUDGE; (R25-30) 25%TS_30%SLUDGE; (R30-20) 30%TS_20%-SLUDGE; (R30-30) 30%TS_30%SLUDGE.

The unsorted and fresh organic fraction of municipal solid waste and inoculum source selected for use in discontinuous reactor were as follows:

Table 1
Composition of six reactors used in the study

Reactor	Denomination	Composition
1	R20-20 (20%TS_20%SLUDGE)	104 g SS-OFMSW + 128 mL SLUDGE + 512 mL H_2O
2	R20-30 (20%TS_30%SLUDGE)	104 g SS-OFMSW + 192 mL SLUDGE + 448 mL H_2O
3	R25-20 (25%TS_20%SLUDGE)	130 g SS-OFMSW + 120 mL SLUDGE + 480 mL H_2O
4	R25-30 (25%TS_30%SLUDGE)	130 g SS-OFMSW + 180 mL SLUDGE + 420 mL H_2O
5	R30-20 (30%TS_20%SLUDGE)	156 g SS-OFMSW + 112 mL SLUDGE + 448 mL H_2O
6	R30-30 (30%TS_30%SLUDGE)	156 g SS-OFMSW + 168 mL SLUDGE + 392 mL H_2O

a. Separately select biowaste fraction, food waste (FW) obtained from a university campus restaurant (Cádiz-Spain). The pre-treatment of the FW was required to provide a suitable refined digested material (selection, drying, crushed and homogenization of particles size of 2–6 mm), in accordance with Forster-Carneiro et al. (2004).
b. Mesophilic digested sludge (SLUDGE) obtained from the "Guadalete" Wastewater Treatment Plant, located in Jerez de la Frontera (Spain). The mesophilic sludge digester was selected with inoculum source coming from the recirculation line of mesophilic anaerobic digesters.

The physical–chemical characteristics of the FW are showed in Table 2. The initial characteristics of FW was: density of 510 kg/m^3, total solid and total organic carbon of 847.0 g TS/kg (84.7%) and 55.8 g DOC/kg, respectively, indicating the abundance of organic matter in the waste (72.4%, measured as VS). C/N ratio was 37.0 and the N–NH_4 contained was 0.13 g N–NH_4^+/kg with an alkalinity of 0.27 g $CaCO_3$/kg.

Before closing, the reactor vessel was loaded with raw feedstock. Water is added in order to adjust the initial total solid contents specified in each assays: 20%, 25% and 30% TS. Later, mesophilic inoculum municipal sludge with 3.2% of TS is added at proportions (20% or 30%) or FW/inoculum of 80/20 and 70/30.

The initial feedstock (FW/SLUDGE) of each reactor is presented in Table 2. As can be seen, all reactors showed appropriate initial density (1020.0–1080.0 kg/m^3). The TS mass fraction in all reactors are presented in the range wanted for this study (288–205 g/kg), with a mean organic content of 17.0–27.8% (measured by VS). Initial DOC was in the range 50.7–63.6 g DOC/L, pH (5.7–6.4) and the C:N ratio was balanced, being around 30–40 and therefore, no nitrogen or phosphorus was added to the reactors. These results are similar to others studies of anaerobic digestion of fruit and vegetable wastes, that showed COD:N ratio around 100:4 (Bouallagui et al., 2005).

2.3. Analytical methods

The parameters analyzed for the characterization were: density, total solids (TS), volatile solids (VS), fixed solids (FS), total suspended solids (TSS), volatile suspended solids (VSS), fixed suspended solids (FSS), pH, alkalinity, total nitrogen Kjeldahl (TNK), total acid (VFA), ammonia nitrogen (N-NH_4), dissolved organic carbon (DOC) and chemical oxygen demand (COD). All analytical determinations were performed according to "Standard Methods" (APHA, 1989), after drying, grinding and dilution of the samples. This procedure is more representative due the semi-solid characteristics of the substrate (Guitian and Carballas, 1975).

TOC analysis was carried out a SHIMADZU 5050 TOC Analyzer for combustion-infrared (5310B) "Standard Methods". TS and VS analysis were by glass filter method he TSS samples were dried in an oven at 105–110 °C and for VSS to the dried ash waste in a furnace at 550 ± 5 °C.

Table 2
Initial characteristic of the initial feedstock at different proportions of total solid and inoculum

Analysis	Food waste (SS_OFMSW)	Digested sludge (Sludge)	R20-20	R20-30	R25-20	R25-30	R30-20	R30-30
Residue								
Density (kg/m^3)	510.0	1090.0	1020.0	1020.0	1040.0	1040.0	1040.0	1040.0
Organic matter (%)	85.3	68.9	98.1	96.5	96.4	95.6	96.5	89.9
Humid (%)	15.1	96.1	79.2	79.5	75.1	74.9	71.2	72.2
Solid (%)	84.7	3.9	20.8	20.5	24.9	25.1	28.8	27.8
TS (g/kg)	847.0	39.0	208.0	205.0	249.0	251.0	288.0	278.0
VS (g/kg)	724.1	26.6	204.1	197.9	240.0	240.0	278.0	250.0
TSS (g/L)	4.4	3.8	6.5	7.7	8.0	7.0	8.1	8.0
VSS (g/L)	4.2	1.6	6.3	7.0	7.5	6.8	7.5	7.4
pH	5.9	7.9	5.7	5.9	6.0	6.1	6.0	6.4
Alkalinity (g $CaCO_3$/L)	0.27	0.54	0.42	0.38	0.58	0.45	0.53	0.52
Total VFA (g AcH/L)	0.49	3.27	0.49	0.58	0.61	0.57	0.38	0.61
N–NH_4 (g/L)	0.13	2.98	0.11	0.19	0.15	0.21	0.22	0.21
TNK (g/L)	14.9	25.4	14.6	14.5	13.9	14.9	15.6	17.0
DOC (g/L)	55.8	24.2	50.7	58.5	56.9	55.2	55.1	53.3
COD (g/L)	47.2	29.2	63.4	66.6	64.8	63.5	59.8	65.4
C:N	37.0	15.7	39.1	38.6	40.2	38.1	36.0	30.7

The alkalinity of samples was determined in COMPACT TITRATOR S^+ Crison Instruments S.A.

Gaseous analyses were determined by removing a representative sample from the reactor. The gas was collected from a TEDLAR bag and measured using a high precision flow gas meter model "WET DRUM TG 0.1 (mbar) – Trallero and Schlee S.A". The biogas composition was carried out by gas chromatography separation (SHIMADZU GC-14B) with a stainless steel column packed with Carbosive SII (diameter of 3.2 mm and 2.0 m length) and thermal conductivity detector (TCD). The injected sample volume was 1 cm^3 and operational conditions were as follows: 7 min. at 55 °C; ramped at 27 °C min^{-1} until 150 °C; detector temperature: 255 °C; injector temperature: 100 °C. The carrier was helium and the flow rate used was 30 mL min^{-1}. A standard gas (by Carburos Metalicos S.A.); composition: 4.65% H_2; 5.3% N_2; 69.9% CH_4 and 20.1% CO_2) was used for the calibration of the system.

The volatile fatty acids (VFA) levels were determined by a gas chromatograph SHIMADZU GC17A equipped with a flame-ionisation detector and capillary column filled with Nikol (polyethylene glycol modified by nitro-terephthalic acid). The temperature of the injection port and detector were 200 °C and 250 °C, respectively. Helium was the carrier gas at 50 mL min^{-1}. In addition, nitrogen gas was used at 30 mL min^{-1} flow rate. In addition, nitrogen gas was used at 30 mL min^{-1} flow rate. VFA were calculated as addition of individual VFA levels. Total acid concentrations were calculated as addition of individual VFA.

2.4. Experimental procedure

The experimental procedure has been developed in two stages:

(a) Selection of the initial performance parameters of the food waste anaerobic thermophilic digestion process: total solid and inoculum contents.
(b) Validation of optimal initial performance parameters in a lab-scale STR20–30 and 5.0 L net volume.

3. Results and discussion

Six lab-batch reactors were tested during a period of 60 days to evaluate the thermophilic anaerobic digestion of FW at three different initial concentrations of total solids in the process, 20% TS, 25% TS and 30% TS and two different initial inoculum percentages (20% and 30%).

3.1. Influence of initial total solid contents and inoculum percentage

3.1.1. Substrates characteristics and biodegradation of food waste

The experiments lasted 60 days. Initially, in the first week, sodium hydroxide (6N) was added to digesters to maintain stable and constant pH values between 7.0 and 8.10. The alkalinity and ammonia levels were adequate to maintain optimal biological activity. In the second week, pH control was not necessary: the pH values were stable and remained constant (between 7.5 and 8.0) until the end of the experiment (day 60). In general, reactors R30-20 and R30-30, with 30% TS, showed lower pH values than other reactors.

Fig. 1 shows reactors performance data: temporal evolution of COD removal (%) in biomethanization processes of FW with different TS and inoculum contents. As can be seen, in the first 20 days of operation (start-up stage), all reactors showed low organic matter biodegradation (as COD removal) due to the acclimation period of biomass-substrate. The greatest efficiency of organic matter removal was observed in the range 20–60 days, coinciding with the stabilization phase. R20–20, R20–30 and R25–20 showed the optimal COD removal, with values near 36.6%, 44.8% and 35.9% of COD removal respectively. VS removals showed similar values to COD removals. Again, the best values of VS removal were for R20–30, followed by R20–20 and R25–20, with 49.7, 43.1 and 41.6% VS removal efficiency. Reactors with 30% inoculum percentage were less efficient, with 23.9–21% COD and 28.8–40% VS

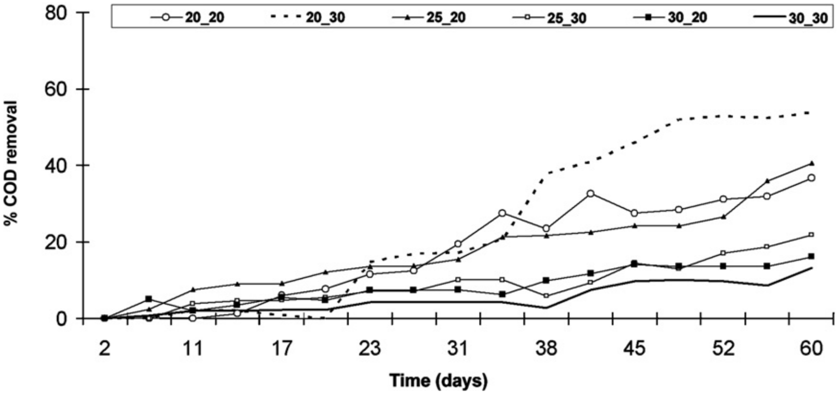

Figure 1. Removal percentage of chemical oxygen demand (COD) in discontinuous lab-reactors.

removal efficiencies. Hence, the organic matter removal in the reactors took place during the first 30 days, and the highest removal efficiencies values were for R20-30 reactor.

3.1.2. Volatile fatty acids degradation

The temporal evolutions of individual acetic and butyric acids and total volatile fatty acids (VFA, as mg/L) are shown in Fig. 2. Volatile acids represent a critical parameter in the operation and control of anaerobic digestion. In this study, all reactors showed an initial stage with hydrolytic and acidogenic activity among 0–20 days with a high fatty acids generations. The total acids oscillation observed later can be attributed to the different biodegradability of organic matter fractions contents in the samples. After the day 20, the hydrolyzed organic matter was transformed to volatile fatty acids, mainly butyric and acetic acids, suggesting the stabilization phase. The concentration of these volatile acids in the digester is determined by their production rate and their removal rate; in this case, the acetic acid removal rate is superior to its production rate.

The higher concentrations of volatile fatty acids generated were for R20-20, R25-20 and R20-30 reactors. The higher values of VFA acids for R20-30 and R25-20 increased to a maximum value of 5563 mg/L and 5468 mg/L respectively, and no destabilization was observed. These results are comparable to those obtained on other researches and studies which have been conducted previously, where approximately 70% of the digester methane was originated from acetate (the most important precursor on which to focus) and the remainder of the digester methane (approximately 30%) was originated mainly from the reduction of dioxide of carbon by hydrogen (Chynoweth et al., 2000).

3.1.3. Biogas generation and methane efficiency

Fig. 3 shows the cumulative methane of different reactors. The average daily cumulative biogas of R20-30, R25-30 and R30-30 amounted to 7136.0, 6308 with 6135 mL and 2820, 2089 and 1120 mL methane content, respectively. These values are higher than those obtained for R20-20, R25-20 and R30-20. Hence, there was an increase in the production with the increase in the inoculum contents and the decrease of total solids percentage, with a maximum cumulative biogas of 7136 mL biogas for R20-30. Reactors with smaller total solids content showed higher methane percentages in the total volume of the biogas.

Reactors R20-20 and R25-20 showed the biggest methane production in the stabilization phase while R20-30 and R25-30 showed higher methane production in the start up and stabilization phases due to higher inoculum percentages (30%). Lopes et al. (2004) published that the inoc-

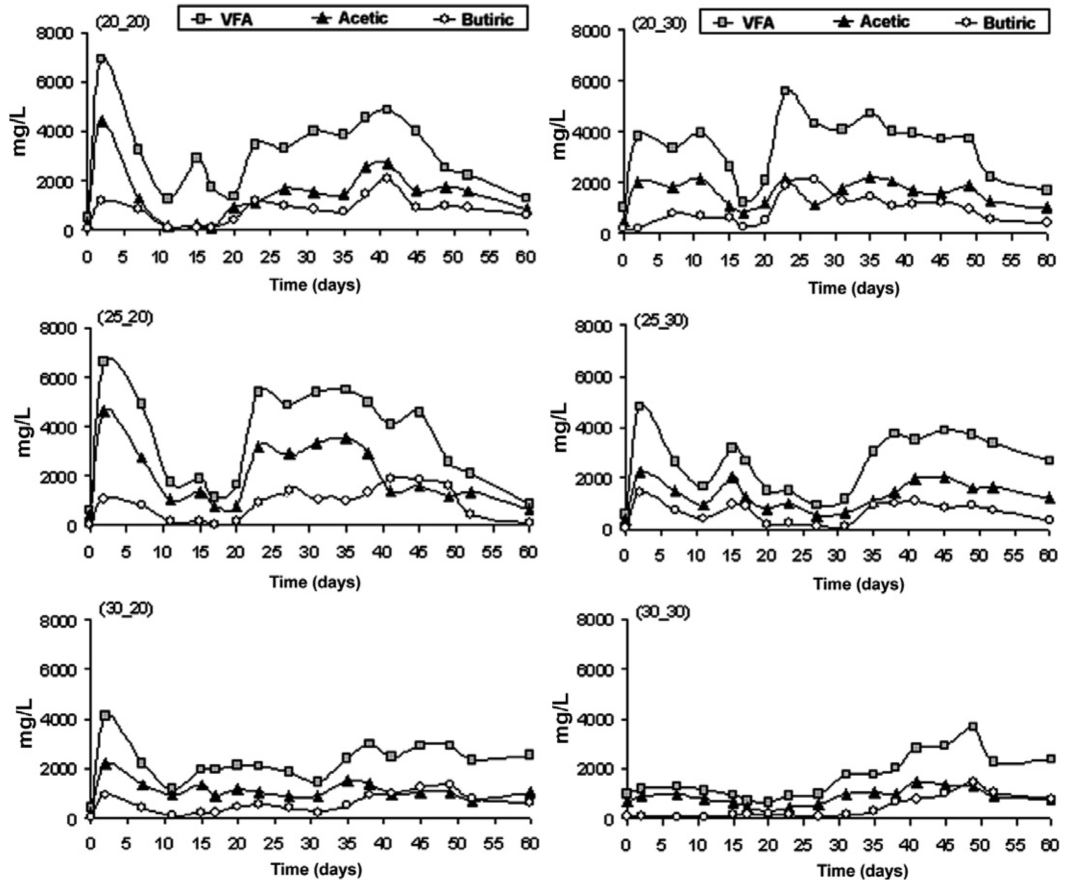

Figure 2. Evolutions of individual (acetic and butyric acids) and total volatile fatty acids, expressed in mg/L, in discontinuous lab-reactors.

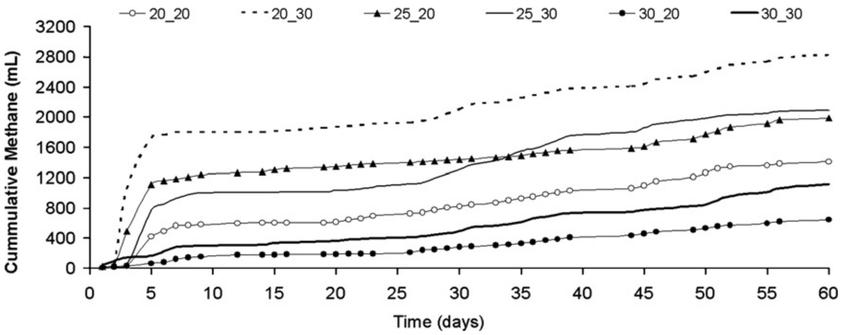

Figure 3. Evolutions of cumulative methane, as mL, in discontinuous lab-reactors.

ulum amount contributed substantially in increasing the amount of methane in the biogas.

Considering only the stabilization phase (among the days 20 and 60), the higher yield of methane was 0.16 L CH_4/g SV (or 0.18 L CH_4/g COD and 0.18 L CH_4/gDOC) for reactor R20-30.

In conclusion, reactors with smaller quantity of solids showed a higher production methane percentage in the total volume of the biogas with a mean percentage of 52% in the stabilization stage (between the days 20 and 60), similar to the results published by Lopes et al. (2004).

Craveiro (1982), while treating solid waste with sewage anaerobically in complete mixture reactors obtained a production of biogas between 0.3 and 0.5 m^3/kg VS added with a methane concentration of 60%. Leite and Povinelli (1999), using anaerobic reactors for the treatment of the fermentable organic fraction of municipal solid waste inoculated with industrial sewage sludge, obtained production of biogas on an average of 0.70 m^3/kg of "in natura" mass applied. Callaghan et al. (2002), while studying the co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure obtained a rate of methane production as 0.37 m^3/kgVS added.

3.1.4. Comparative process efficiency

Table 3 shows a summary of performance data at the end of the process for all six reactors studied. In all cases, COD removals were similar to VS removals. The highest methane production was observed in R20-30 after the second week of inoculation, while R30-30 only showed slight generation efficiency after the day 25. Over 60 day's operation process, the greatest cumulative biogas or methane was obtained for R20-30 reactor, followed to R20-20 reactor and R25-20, with values of 7136, 6495 and 6308 L biogas cumulative, respectively.

Table 3
Summary of performance data of discontinue reactors after 60 days of study

Reactor	Organic matter removal			Cumulative biogas and methane	
	VS (%)	DOC (%)	COD (%)	Biogas (after 60 days)	Methane (after 60 days)
R20-20	43.1	37.4	36.6	6495	1406
R20-30	49.7	44.3	44.8	7136	2820
R25-20	41.6	36.6	35.9	5590	1985
R25-30	40.0	26.0	21.9	6308	2089
R30-20	28.8	20.1	21.0	4863	647
R30-30	31.6	26.7	23.9	6135	1120

Considering only the stabilization stage (20–60 days), the reactor R20-30 was the most effective operation conditions, showing a methane yield of 0.49 L CH4/g VS. Jerger and Tsao (1987) determine the upper theoretical methane yields for several different biomasses and waste feedstock and found similar results for municipal solid waste (0.512 L CH4/kg VS) and primary sludge (0.793 L CH4/kg VS).

3.2. Performance of start up strategy in STR20-30 reactor (20% TS and 30% of inoculum)

The ratio FW: inoculum in reactor R20-30 favoured the start up phase of dry anaerobic digestion of food waste when compared with the others conditions tested. In order to validate the selected conditions, lab-digester of 5.0 L was operated with 20% of total solid and 30% of inoculum treating food waste (denominate STR20-30).

The initial characteristics of FW were 55.8 g/L of DOC and 14.9 g/kg of TNK. The carbon and the nitrogen, indispensable for the growth and the diversification of the biomass, were analyzed and the result was 37.0. Others analytical parameters indicated the biodegradability of complex substrate (OFMSW). The bioprocess conversion efficiency profiles over time of organic matter were shown in the Fig. 4 (calculated as VS and TS removals (VS_r and TS_r) and as COD and DOC removals (COD_r and DOC_r). As can be seen, the initial total solid concentration in STR-20-30 was 20.0 g TS/L. Both TS and VS values showed slow and constant decrease since the first day, resulting volatile solids removal proximally to 44.2% VS_r and 55.0% of COD_r after 60 days.

Fig. 5 shows the temporal evolution of pH, alkalinity, N–NH_4 and acid/alkalinity rate. The pH control with 50 mL of hydroxide of sodium (6N) was necessary during the first 10 days. The parameters pH, N–NH_4, acid/alkalinity ratio and alkalinity showed adequate values to maintain stable process. The hydrolytic phase occurred in the first

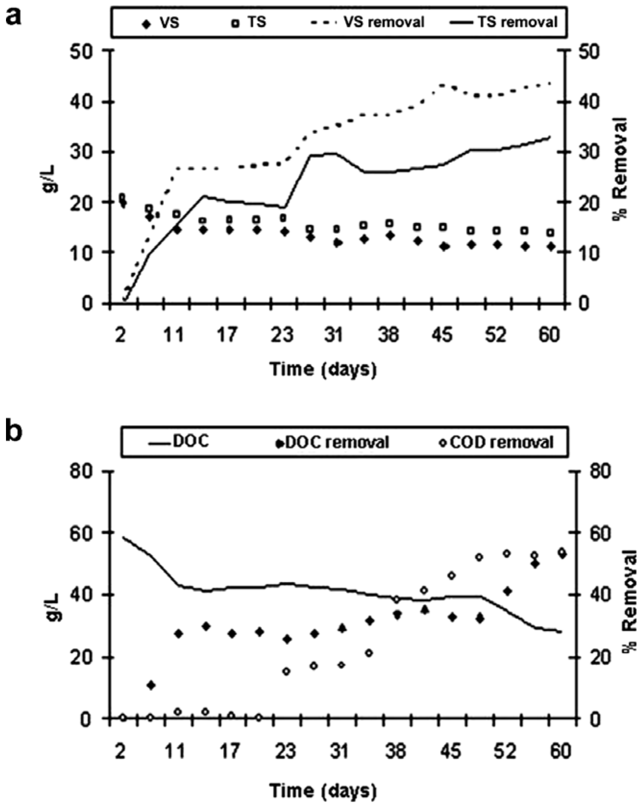

Figure 4. Removal percentages of: (a) total and volatile solids; (b) chemical oxygen demand (COD) and dissolved organic carbon (DOC), in reactor R20-30.

two weeks, characterized by increase of the N–NH_4 levels from 1.78 up to 2.40 g/L and of alkalinity of 0.22 up to 1.69 g/L. These results were indicative of a strong microbiological activity that is translated in a great increment of the acidity of the means favoured by the hydrolysis of the organic compounds.

The higher total acid concentrations were observed in the start up phase between the days 1 and 15 (Fig. 6). In this stage, the high molecular weight compounds were converted into intermediate VFA, mainly propionic and butyric acids by acidogenic bacteria. Acetic acid, the major intermediate in methanogenesis was formed through the degradation of propionic and butyric acids and through the oxidation of hydrogen, process involving different acetogenic populations. The methanogenesis and methane gas production increased while the carbon dioxide and VFA concentrations decreased.

Fig. 7a shows the evolution of biogas (CH_4, CO_2 and H_2), as percentage. The initial methane production increased when the production of hydrogen (20% of total volume of biogas) decreased. Methane can only be formed by specific methanogenic bacteria which use acetic acid or hydrogen. Considering only the stabilization phase (20–60 days), the biogas produced had higher methane concentration of 49.9% during the stabilization phase (20–60 day).

The anaerobic digestion of several OFMSWs generate methane, carbon dioxide and other trace gases amounts like hydrogen sulphide and hydrogen, and humus like residue. The formation of hydrogen sulphide was null in this study and it is not detected by the team, because the precedent food waste of the restaurant does not contain enough quantity of sulphur.

Fig. 7b shows the biogas and methane production (as L/day) and the evolution of cumulative biogas and methane (as L). Higher production of biogas was observed in the start up phase. The reactor reached the higher daily generation of biogas (4.3 L/day) in the first 20 days and higher values of methane yield of 0.22 L CH_4/g VS. After the day 20, the process was characterized by methanogenic phase or stable phase, where the acidity continuous increases, fundamentally due to butyric acid, and decreasing the acetic acid. The cumulative biogas and methane yield showed a slowly increase, day after day, until reached maximum values of 85.1 L and 13.8 L, respectively.

Finally, a protocol was proposed to enhance the start up phase for dry-thermophilic anaerobic digestion, based on the conclusions obtained in previous results of this experiment and previous works (Forster-Carneiro et al., 2006). The protocol consisted: (a) to dry and to shred the samples of organic fraction in cross-beater mill to average particle

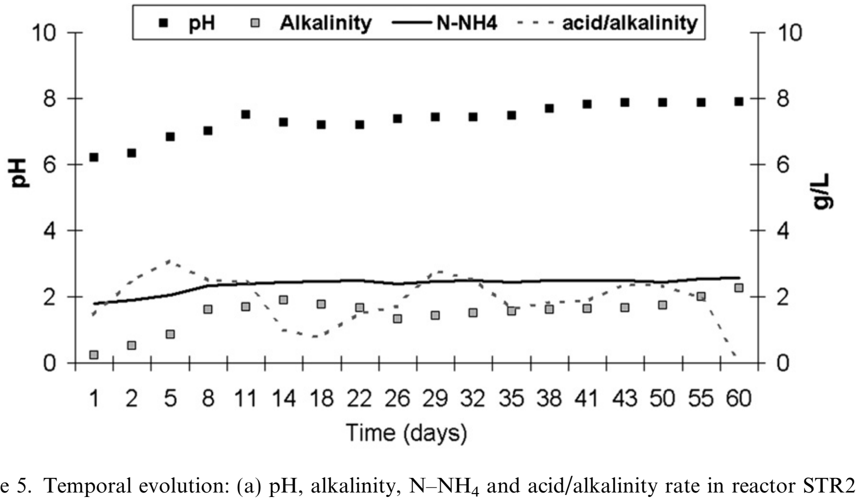

Figure 5. Temporal evolution: (a) pH, alkalinity, N–NH_4 and acid/alkalinity rate in reactor STR20-30.

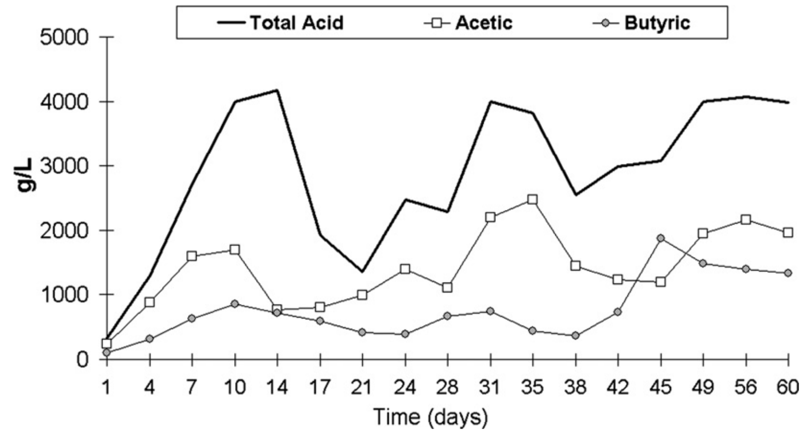

Figure 6. Temporal evolution of total acid in reactor STR20-30.

size of about 2 mm, obtaining a homogenous sample; (b) to add mesophilic sludge coming from Waste WaterTreatment Plant as inoculum; (c) to dilute the organic samples until reach dry conditions (20% of total solid) and 30% of inoculation; (d) to control the pH, fundamentally during the hydrolysis phase.

4. Conclusion

The best performance for food waste biodegradation and methane production was the reactor with 20% TS and 30% of inoculum source. The FW exhibit the classical waste decomposition pattern with a fast start up phase

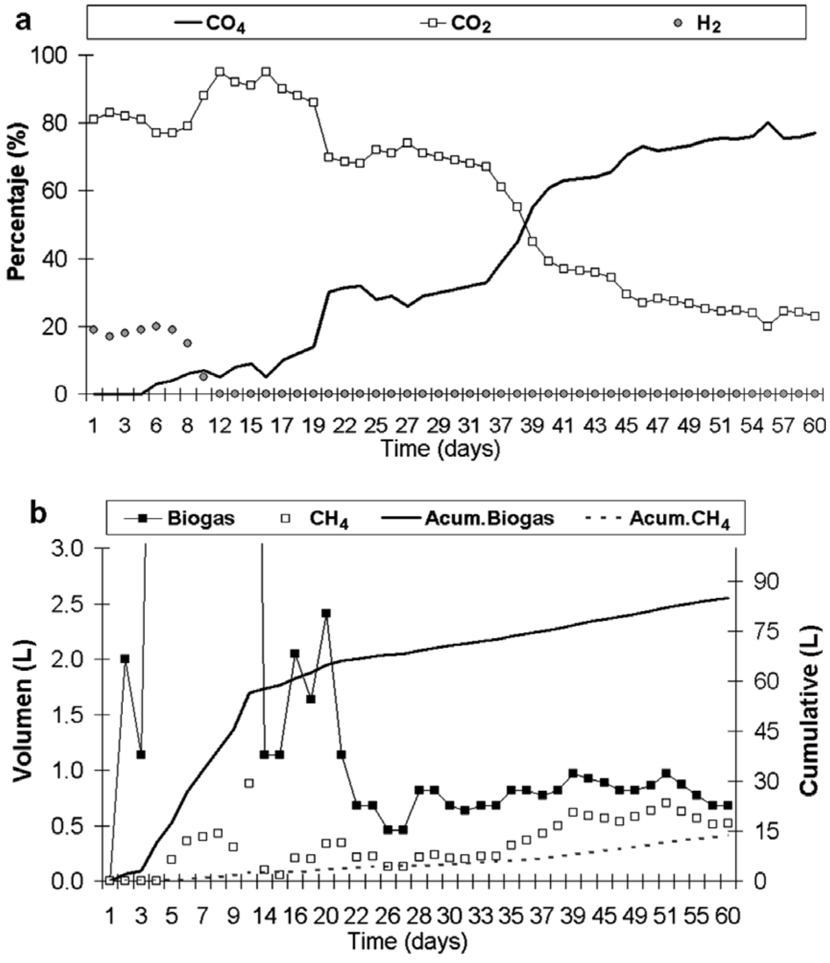

Figure 7. The biogas profile data: (a) percentage of CH_4, CO_2 and H_2; (b) Biogas and methane production and cumulative biogas and methane in reactor STR20-30.

beginning within 0–5 days, an acclimation stage (acidgenic/acetogenic phases) between days 5 and 20–30 and a subsequent stabilization phase. Under these conditions, the FW digestion reaches 30% VS_r and approximately 30% DOC_r, with higher daily generation of biogas (4.3 L/day) in the first 20 days and higher values of methane yield of 0.22 L CH_4/g VS. The process was completed and a high level of cumulative methane production (6.9 L) was achieved in less than 60 days.

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