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Thermophilic anaerobic digestion of source-sorted organic fraction of municipal solid waste

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Abstract

The influence of different organic fraction of municipal solid wastes during anaerobic thermophilic (55 °C) treatment of organic matter was studied in this work: food waste (FW), organic fraction of municipal solid waste (OFMSW) and shredded OFMSW (SH_OFMSW). All digester operated at dry conditions (20% total solids content) and were inoculated with 30% (in volume) of mesophilic digested sludge. Experimental results showed important different behaviours patterns in these wastes related with the organic matter biodegradation and biogas and methane production. The FW reactor showed the smallest waste biodegradation (32.4% VS removal) with high methane production (0.18 LCH4/gVS); in contrast the SH_OFMSW showed higher waste biodegradation (73.7% VS removal) with small methane production (0.05 LCH4/g VS). Finally, OFMSW showed the highest VS removal (79.5%) and the methane yield reached 0.08 LCH4/g VS. Therefore, the nature of organic substrate has an important influence on the biodegradation process and methane yield. Pre-treatment of waste is not necessary for OFMSW.

Keywords: Anaerobic digestion; Food waste; Organic fraction of municipal solid waste; Thermophilic; Methane

1. Introduction

Anaerobic digestion has been suggested as an alternative method of removing the high-concentration organic waste. Several research groups have developed anaerobic digestion processes using different organic substrates (Pérez et al., 1997; Gallert et al., 2003; De la Rubia et al., 2006a; Forster-Carneiro et al., 2007a). The advantages of such processes over conventional aerobic processes are a low energy requirement for operation, a low initial investment cost and a low sludge production (Nguyena et al., 2007). In addition, the anaerobic digestion process produces biogas, which can be used as a clean renewable energy source (Bouallagui et al., 2003; Pérez et al., 2005). In Europe, increasing numbers of biogas plants (BGPs) employing anaerobic digestion use food waste and manure as energy sources.

Anaerobic digestions can be developed at different temperature ranges including mesophilic temperatures (approximately 35 °C) and thermophilic temperatures ranging from 55 °C to 60 °C. Conventional anaerobic digestion is carried out at mesophilic temperatures, that is, 35–37 °C. Several new processes have been reported for upgrading sludge digestion using thermophilic anaerobic digestion (55 °C) and these represent an important alternative to mesophilic anaerobic digestion (35 °C) (Zabranska et al., 2000; De la Rubia et al., 2005). The thermophilic temperature range is worth considering because it will lead to give faster reaction rates, higher gas production, and higher rates of the destruction of pathogens and weed seeds than the mesophilic temperature range. However, the thermophilic process is more sensitive to environmental changes than the mesophilic process (De la Rubia et al., 2006b).

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Nomenclature

MSW	municipal solid waste
FW	food waste
SH-OFMSW	shredded organic fraction municipal solid waste
OFMSW	organic fraction municipal solid waste
TS	total solid (g/kg)
VS	volatile solid (g/kg)
TSS	total suspended solid (g/L)
VSS	volatile suspended solid (g/L)
TOC	total organic carbon (g/L)
DOC	dissolved organic carbon (g/L)
COD	chemical oxygen demand (g/L)
TKN	total kjeldahl nitrogen (mg/kg)
NH_4–N	ammonia nitrogen

Two main technologies have been used for the rapid treatment of organic fraction of municipal solid wastes (OFMSW): sequential leach-bed anaerobic processes (ÓKeefe and Chynoweth, 2000) and CSTR reactors (Pavan et al., 2000) or Batch systems (Lissens et al., 2001). Both technologies have very simple designs and there are numerous reports on their use (Kim et al., 2002). However, the CSTR systems are the least expensive solid waste digesters for simplest designs. It is superior and more economical than other competing technologies because it is grown in a similar anaerobic environment (Kim et al., 2002). The system has high potential for application in developing countries (Lissens et al., 2001).

Also, the large majority of industrial applications use one-stage systems and these are evenly split between "dry" systems (wastes are digested as received) and "wet" systems (wastes are slurred to about 12% total solids). However, the "dry" designs or high-solid (Nguyena et al., 2007) have proven reliable due to their higher biomass concentration, controlled feeding and spatial niches (Ahring, 1992; Hartmann and Ahring, 2005). Moreover, from a technical viewpoint, the "dry" systems are more robust and flexible than "wet" systems.

Municipal solid waste (MSW) is a serious problem for urban communities. Organic solids are present in very large quantities as products or waste from agriculture, the food industry and market waste. Spain generates approximately 24 millions tonnes of MSW annually (Mace et al., 2005). According to the data published by the National Plan of Urban Wastes (NPUR, 2000–2006), 40–45% of total MSW is the organic fraction of municipal solid waste (OFMSW). The composition of OFMSW is influenced by several factors, including regional differences, climate, collection frequency, season, cultural practices, as well as changes in composition (Tchobanoglous et al., 1997). At this respect, numerous papers have focussed on aspects of anaerobic digestion biodegradation of the OFMSW according to its origin: e.g., market waste (Mata-Alverez et al., 1993), fruit and vegetable (Bouallagui et al., 2005), household waste (Krzystek et al., 2001), food waste (Kim et al., 2000), kitchen waste (Rao and Singh, 2004), biowaste (Gallert et al., 2003) and organic fraction of municipal solid waste (OFMSW) (Bonzonella et al., 2005).

Actual researches on anaerobic digestion reports that substantial differences were observed in the methane yields and kinetics depending of the food waste or MSW type (Rao and Singh, 2004). However, few reports can be found on the study of dry anaerobic digestion of food waste, 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 waste nature is not extensively investigated yet.

The aim of this paper was to study the anaerobic digestion process for three types of organic substrates: food waste (FW), shredded organic fraction of municipal solid waste (SH-OFMSW) and organic fraction of municipal solid waste (OFMSW). The emphasis was to evaluate the biodegradation process and to evaluate the influence of shredded in the pre-treatment of municipal solid waste. In addition, the paper presents the performance parameter results (organic matter degradation and methane production rate and methane yield) for each type of MSW.

2. Methods

2.1. Anaerobic reactors

The assays were carried out in batch discontinuous 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) and utile volume of 0.715 L (or 65%). 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% TS and 30% inoculum percentage at single phase thermophilic (55 °C) condition.

2.2. Samples pre-treatment and reactors preparation

The study is programmed to evaluate the thermophilic anaerobic digestion of three different organic substrates:

(1) shredded food waste (FW); (2) shredded organic fraction of municipal solid waste (SH-OFMSW); (3) organic fraction of municipal solid waste (OFMSW).

The unsorted and fresh organic fractions and inoculum source selected for use in discontinuous reactor were as follows:

(a) FW: 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, shredded and homogenization of particles size of 2–6 mm), in accordance with Forster-Carneiro et al. (2004).
(b) SH-OFMSW: shredded municipal waste from Las Calandrias MSW Treatment plant – Jerez de la Frontera – Cadiz – Spain. Pre-treatment of this waste was required to provide a suitable refined digested material (selection, drying, shredded particles of 2–6 mm size and homogenized), in accordance with Forster-Carneiro et al. (2004).
(c) OFMSW: organic fraction of municipal solid waste from the trommel of 30 mm of Las Calandrias MSW treatment plant placed in Jerez de la Frontera – Cadiz – Spain.
(d) 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.

All reactor vessels were loaded with raw feedstock and inoculated with mesophilic municipal sludge (30%) and water was added to obtain the desired total solid percentage (20% ST) in accordance with Forster-Carneiro et al. (2007b):

(a) FW: 104 g food waste + 192 mL SLUDGE + 448 mL H_2O;
(b) SH-OFMSW: 108 g shredded municipal waste + 192 mL SLUDGE + 448 mL H_2O;
(c) OFMSW: 57.7 g municipal waste + 192 mL SLUDGE + 448 mL H_2O.

2.3. Analytical methods

The parameters analyzed for the characterization of substrates were as follows: 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 kjeldahl nitrogen (TKN), total acidity, ammonia nitrogen (NH_4–N), total organic carbon (TOC) and chemical oxygen demand (COD).

The evolutions of anaerobic thermophilic digestion of FW, SH-OFMSW and OFMSW substrates were: (a) for FW and SH-OFMSW digesters, daily analyses were performed on the leachate: TS, VS, FS, COD, DOC, pH, alkalinity, NH_4–N. Also, biogas production and composition was measured during all the study; (b) for OFMSW digester it was not possible to obtain representative leachate samples during the evolution of the process. Therefore, only initial and final values of the analytical parameters were considered. Biogas production and composition was measured during all the study.

All analytical determinations were performed according to "Standard Methods" (APHA, 1995).

The alkalinity of each sample was analysed using a COMPACT TITRATOR S + (Crison Instruments S.A.). The TOC and DOC analyses were carried out using a SHIMADZU 5050 TOC Analyzer for combustion-infrared (5310B) from the "Standard Methods".

Gas produced in the reactor was collected in a 40 L Tedlar Bag, with biogas samples obtained on a daily basis and then analysed. The volume of biogas was measured directly using a WET DRUM TG 01 (mbar) high precision gas flow meter (Trallero and Schlee S.A.) through a CALI 5 BOND™ meter displacement bag (Trallero and Schlee S.A.). The biogas composition was analysed by gas chromatographic separation (SHIMADZU GC-14B) using a stainless steel column packed with Carbosieve SII (3.2 mm diameter and 2.0 m length) and a thermal conductivity detector (TCD). The injected sample volume was 1 cm^3 and the operating conditions were as follows: 7 min at 55 °C; ramped at 27 °C min^{-1} to 150 °C; detector temperature: 255 °C; injector temperature: 100 °C. The carrier gas was helium and the flow rate used was 30 mL min^{-1}. A standard gas (from Carburos Metálicos S.A.) was used to calibrate the system and this had the following composition: 4.65% H_2; 5.3% N_2; 69.9% CH_4 and 20.1% CO_2).

Total acidity concentration was calculated by addition of individual volatile fatty acid levels (VFA). The fatty acid levels were determined by gas chromatography – SHIMADZU GC-17A equipped with a flame-ionization detector and capillary column filled with Nukol (polyethylene glycol modified by nitroterephthalic acid). The injection port and detector temperatures were 200 °C and 250 °C, respectively. Helium was the carrier gas at 50 mL min^{-1}. The nitrogen flow rate was 30 mL min^{-1}. Total VFA was calculated by the addition of individual VFA levels.

3. Results and discussion

Three lab-batch reactors were tested during a period of 90 days to evaluate the thermophilic anaerobic digestion of the organic substrates. The pre-treatment was performed to improve the consistency of the FW and SH-OFMSW and to allow taking representative samples in the laboratory digester (1.1 L). For OFMSW, pre-treatment was not performed and the evolution of this digester was determined only considering initial and final samples of the process and biogas generation and composition during the digestion.

3.1. Substrates characterization

The initial substrates characterizations (FW, SH-OFMSW and OFMSW) and initial composition of each reactor (WASTE/SLUDGE) are presented in Table 1.

The initial raw feed of all there digester showed adequate density (1040–1100 kg/m^3) and total acidity level (567.8–733.0 mg/kg). All three wastes can be considered high-solid substrates: water has been added to obtain the desired total solid percentage (20% ST). The majority of the total solids present in the FW digester were volatile organic solids (204.0 g/kg of VS) or 90.4% of the total solid. The OFMSW contained a large amount of inorganic material, mainly from soil/sand and small inorganic particles. DOC analyses were 90.4, 59.7, and 64.7 g/L for the FW, SH-OFMSW and OFMSW digesters, respectively. The average of organic matter was 52.9% for SH-OFMSW and 52.6% for OFMSW. Consequently, the C:N ratio were 23.4 for FW, 13.2 for SH-OFMSW and 7.8 for OFMSW and therefore, no nitrogen or phosphorus was added to the reactors. The C:N value of FW digester is similar to published by others studies of anaerobic digestion of fruit and vegetable wastes, that showed COD:N ratio around 100:4 (Bouallagui et al., 2005).

3.2. Biodegradation analysis

3.2.1. Evolution of VS

The temporal VS changes in FW and SH-OFMSW digesters are presented in Fig. 1. Discontinuous vertical lines have been included to differentiate the degradation phases observed in the process: the left area of the graph corresponds to the hydrolytic and acidogenic stages (start up phase); the central part, corresponds to the development of the methanogenic stage (stable phase); and the right area is related with the finished phase of the process, due to the end of the biodegradable organic matter.

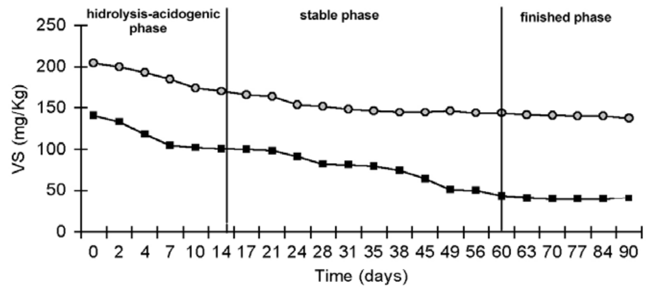

Fig. 1. Temporal evolution of VS (mg/kg) in the digesters.

FW reactor showed a poor VS reduction during days 10–65, reaching constant values until the end of the assays (25.0–30.0%). SH-OFMSW digester showed an important removal of VS in two ranges: between 15–25 and 40–50 days. The heterogeneity of this waste SH-OFMSW explains this fact. The percentage of VS removal reached 29.4% for FW digester (34.9% VSS removal) and 71.6% for SH-OFMSW (71.0% VSS removal) in 60 days. At 90 days, VS removal showed 32.4% for FW and 73.7% for SH-OFMSW. These results indicate that the organic matter content in SH-OFMSW (50.0% approximately) was removed in 40 days, while the FW needed 90 days to reach the same percentage removal.

3.2.2. Evolution of pH and DOC

The start up phase happened among the days 2 and 10. In this period, important variations of pH values were observed in FW reactor. The pH values of SH-OFMSW reactor oscillated from 8 to 7.5 approximately. Both reactors showed pH oscillations in the start up phase. An adjustment of the pH until 8.5 with hydroxide sodium (6 N) was

Table 1
Initial mean characteristic of the organic wastes (residue) and initial raw feed characteristic of the reactors

Parameter	Residue			Raw feed		
	Food waste (FW)	Shredded municipal waste (SH-OFMSW)	Municipal waste (OFMSW)	Food waste (FW)	Shredded municipal waste (SH-OFMSW)	Municipal waste (OFMSW)
Density (kg/m^3)	500.0	328.0	361.0	1100.0	1060.0	1040.0
Organic matter (%)	90.4	52.9	52.6	92.7	69.0	57.9
Wed (%)	13.2	18.1	19.0	78.0	79.6	81.0
Solid (%)	86.8	81.9	81.0	22.0	20.4	19.0
TS (g/kg)	868.0	819.0	810.0	220.0	204.0	190.0
VS (g/kg)	785.0	433.5	426.0	204.0	140.8	110.0
pH	7.0	7.6	7.3	8.1	7.8	7.9
Alkalinity (g/L)	0.2	0.30	0.51	0.90	1.40	1.65
Total acid (mg/L)	0.46	1.35	0.72	0.57	0.73	0.69
$N–NH_4$ (g/kg)	0.11	0.67	1.06	1.49	1.56	1.36
Total-N (g/kg)	12.75	22.0	34.0	2.30	3.03	4.31
DOC (g/kg)	89.9	52.2	64.7	90.4	59.7	64.7
COD (g/kg)	91.9	57.6	73.8	98.0	70.1	76.5
Total-P (g/kg TS)	2.9	1.12	1.17	1.40	1.15	0.83
P (P_2O_5) (g/kg ST)	0.12	0.05	0.05	0.06	0.05	0.03
Carbon (%)	45.1	30.7	30.5	53.8	40.0	33.6
C:N (Organic matter)	35.4	10.4	8.9	23.4	13.2	7.8

necessary to control the pH at optimal values for the thermophilic digestion processes between the day 2 and 10. After the day 10, the evolution of pH remained stable and the addition of NaOH was not necessary. In this way, the pH and alkalinity (between 0.1 and 0.3 g $CaCO_3$/L) showed suitable values in order to maintain optimal biologic activity in both digesters. The pH increased since 6.1–8.7 between the day 15 and 60 (stable phase) in FW reactor. For SH-OFMSW, the pH remained constant in the range 8.5–8.9 in the stable and finished phases.

Temporal evolution of DOC concentrations (as mg DOC/L) and DOC removal percentages in FW and SH-OFMSW digesters are shown in Fig. 2. The initial DOC concentrations were 90378.1 mg DOC/L and 59655.0 mg DOC/L for FW and SH-OFMSW, respectively. Initially, a slight descend of DOC values were observed in the first two weeks for FW (Fig. 2a) and in the first week for SH-OFMSW (Fig. 2b) due the degradations of several organic complex matters to other compounds without reduction of DOC parameter. In the stable phase, DOC values showed similar evolutions in both digesters. In this phase, DOC concentrations and DOC removal percentages were directly related with the pH and the microbial activity. The pH levels increases while the DOC levels decreased in the operational process. Over 90 days operating period, the SH-OFMSW reactor showed the greatest efficiency of DOC removal with values near to 73.3% while FW showed only 56.5% DOC removal.

VS removals showed similar behaviour to DOC and COD removals in both digesters. Hence, the organic matter removal in the FW reactor was slow and constant during all the experiment. In contrast, organic matter removal in SH-OFMSW digester was 40–50.0% and took place during the first 40 days.

3.2.3. *Volatile fatty acids degradation and acidity evolutions*

The total acidity and acetic and butyric acids evolutions is presented in Fig. 3. Different process stages were observed in these evolutions in function of the waste type:

FW digester: the first stage (start-up stage) was detected between 1 and 10 days, characterized for a high volatile acids production. Later, 10–30 days, the total acidity increased until reaching 4325 mg/kg, where the increase in total acidity is due to the increase in short chain fatty acids (mainly acetic acid). The acidity/alkalinity ratio also

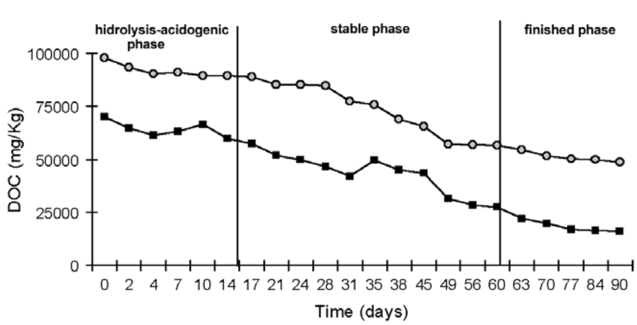

Fig. 2. Changes of DOC (mg/kg) in the digesters.

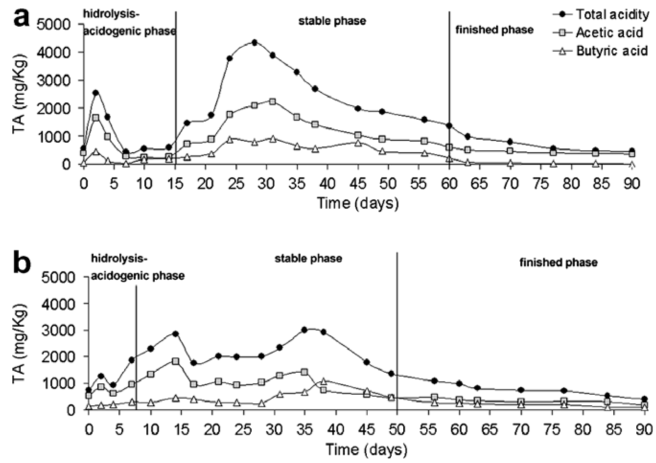

Fig. 3. Temporal evolution of total acidity (mg/kg), acetic acid and butyric acid (mg/kg) in the digesters.

increased in this stage. In a second stage, later day 30, total acidity and VFA (acetic and butyric acids) showed a typical evolution of anaerobic digestion process. Butyric concentrations were smaller to acetic values, reaching a maximum value of 1083 mg/kg in total acidity (2678.0 mg/kg) (Fig. 3a). All stages of the anaerobic digestion process were detected in this digester: hydrolysis-acidogenic, methanogenic and finished phase, after day 60–70.

SH-OFMSW digester: total acidity concentrations showed an increase during the range 2–18 days, reaching maximum values of 2842 mg/kg. Later, the values decrease until 987 mg/kg in the day 55. The values of butyric acid were higher than acetic acid values only among the days 38 and 49 of essay (Fig. 3b). The values of alkalinity and acidity/alkalinity ratios remaining constant, decreasing at the end of the process, in the finished phase.

The total VFA acids concentration for FW increased to a maximum of 4325.0 mg/kg, and not destabilization was observed. These results were compared with other researches and studies which have been conducted previously, where approximately 70% of the digester methane was originated from acetate and approximately 30% was originated mainly from the reduction of dioxide of carbon by hydrogen (Chynoweth et al., 2001).

As can be seen, temporal evolution of alkalinity (mg/kg) and NH_4–N (mg/kg) shows that there were substantial differences among FW and OFMSW digesters (Fig. 4). Ammonia values were in the range 1400.0–2000.0 mg/kg during the first stage (2–40 days) in FW digester. In this case, the methanogenic activity increased with the decrease in ammonia concentration, indicating the initial of stable phase. Later, the values remained constant until the end of the assays, reaching 2500.0 mg/kg. For SH-OFMSW digester, the ammonia values remained in the range 1100.0–1900.0 mg/kg during all the experiment. The inhibition for ammonium (Angelidaki and Ahring, 1994; Hansen et al., 1998) was not observed in both digesters, almost the values were next o the inhibitory values published by Angelidaki and Ahring (1994) and Hansen et al. (1998).

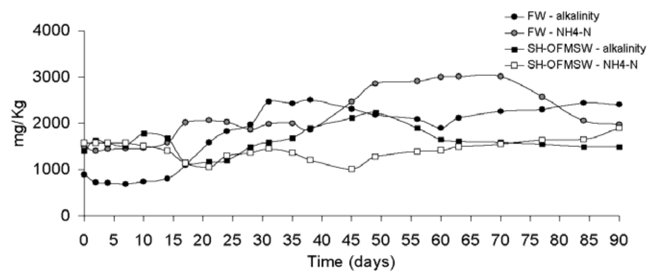

Fig. 4. Evolution of alkalinity and NH_4–N (mL/kg) in the digesters.

3.2.4. Biogas generation and methane efficiency

Biogas production was measured and cumulative methane production from each system was calculated. Fig. 5 showed great volume of the initial methane production for SH-OFMSW and small quantities for the FW reactor in the start up phase. In the stable phase the biogas production was 134.0 mL/mL d for FW digester (20–60 days) and 88.3 mL/mL d in SH-OFMSW digester (5–50 days) (Fig. 5a). The cumulative methane was 3591.4 mL CH_4 and 2039.4 mL CH_4 after 60 days, and 4045.2 mL CH_4 and 2330.0 mL CH_4 after 90 days for FW and SH-OFMSW, respectively (Fig. 5b).

The Fig. 5 shows in both reactors (FW and SH-OFMSW) two different phases:

Start-up stage: the initial hydrolysis stage was observed in the first week. In the second week, the acidogenic stage was presented with a high biogas and methane production (reaching 60–70% of total biogas). The methane generation was null for FW and very small for SH-OFMSW. The cumulative methane showed a fast increase in SH-OFMSW digester due the high biogas generation. Hydrogen percentages reached levels proximally to 10% during the period 2–6 days in two digesters. Later, hydrogen concentrations were not detected.

Stabilization stage: methane production reached constant values at day 30. The maximum methane percentage in the biogas reached 76.7% and 68.5% for FW and SH-OFMSW, respectively. The maximum values of biogas generation were 227.3 mL and 136.0 mL for FW and SH-OFMSW, respectively. Cumulative biogas after 60 days for FW and SH-OFMSW reached 6088.0 mL biogas and 5507.1 mL biogas, respectively, and 6948.0 mL and 5822.0 mL after 90 days.

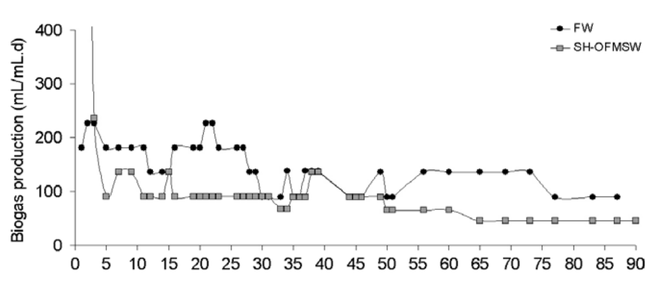

Fig. 5. Biogas and methane production in the digesters.

3.3. Influence of shredded in the pre-treatment of municipal solid waste

SH-OFMSW and OFMSW digesters were tested during a period of 90 days to evaluate the influence of shredded in the pre-treatment of municipal solid waste from treatment plant in anaerobic digestion at dry and thermophilic conditions. The SH-OFMSW digester was pre-treated (dry and shredded) previously at the sealed of the reactor

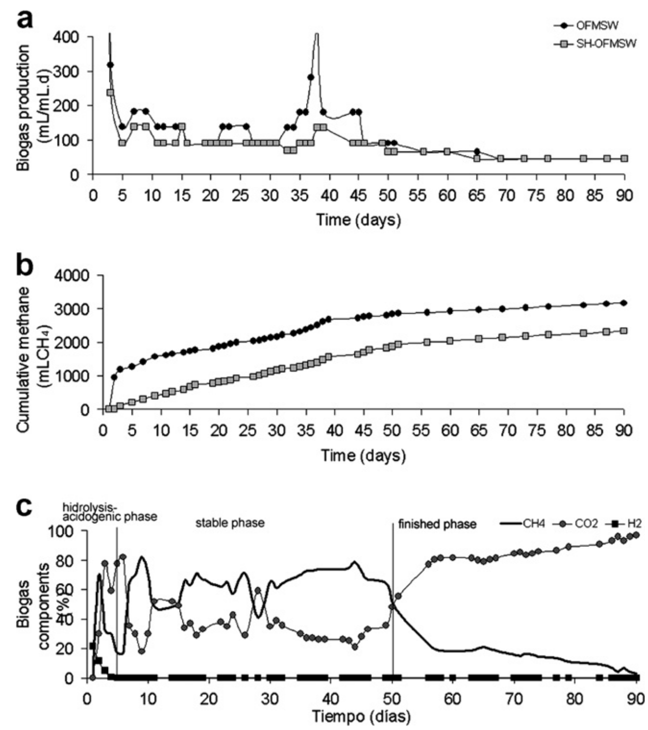

Fig. 6. Biogas profile data in the SH-OFMSW and OFMSW digesters: (a) biogas production; (b) cumulative methane; and (c) biogas components.

Table 2
Final values of the different analytical parameters in reactors

Analysis	Final composition digester		
	Food waste (FW)	Shredded municipal waste (SH-OFMSW)	Municipal waste (OFMSW)
Density (kg/m^3)	1080.00	1050.00	1030.00
Organic matter (%)	75.0	47.4	61.6
Wed (%)	78.00	92.2	96.3
Solid (%)	18.40	7.8	3.7
TS (g/kg)	184.00	78.0	36.7
VS (g/kg)	138.00	37.0	22.6
pH	8.3	8.9	8.5
Alkalinity (g/L)	2.40	1.49	1.77
Total acid (mg/L)	0.46	0.40	0.79
N–NH_4 (g/kg)	1.98	1.89	1.15
Total-N (g/kg)	28.0	45.0	47.0
DOC (g/kg)	39.3	15.9	22.6
COD (g/kg)	48.8	21.6	21.3
Total-P (g/kg TS)	1.08	0.07	0.10
Carbon (%)	43.5	27.5	35.7
C:N (organic matter)	15.5	6.1	7.6

Table 3
Main results of the thermophilic anaerobic reactors for methane production yield and degradation performance of: FW, SH-OFMSW and OFMSW

Digester	Methane production yield (L/g)			Organic Matter removal (%)					
	CH_4/VS	CH_4/COD	CH_4/DOC	TS	VS	TSS	TVS	COD	DOC
FW	0.18	0.14	0.15	16.4	32.4	46.2	47.0	50.2	56.5
SH-OFMSW	0.05	0.06	0.06	61.7	73.7	72.1	71.8	69.2	73.3
OFMSW	0.08	0.09	0.09	80.6	79.4	33.3	30.7	72.2	74.4

(Forster-Carneiro et al., 2004). The pre-treatment was performed to improve the consistency of the SH_OFMSW and to allow taking samples in the laboratory digester (1.1 L).

3.3.1. Comparative process efficiency

The gas composition and production of both reactors SH-OFMSW and OFMSW can be seen in Fig. 6. Fig. 6a showed great volume of the initial methane production for OFMSW and smaller quantities for SH-OFMSW digester in the start up phase. In the reactor OFMSW the mean gas production was 225.0 mL/mL d and the mean methane production of 132.3 mL/mL d in all experiments. The cumulative biogas and methane for SH-OFMSW and OFMSW were 5822.1 mL biogas and 9926.5 mL biogas and 2330.3 mL CH_4 and 3162.7 mL CH_4, respectively, after 90 days (Fig. 6b). As can observe that, the methane production was not very different among two reactors studied.

The biogas components are shown in Fig. 6c. Methane was generated since the second day until day 60 in which the methane production was null. The methane gas concentration was proximally of 43.7% CH_4 for SH-OFMSW digester during the stable process (between the day 7 and 45) and 65.6% CH_4 for OFMSW in the stable phase (between the day 7 and 50). According Castrillón et al. (2002) the absence of oxygen of the biogas in anaerobic treatment of MSW landfill leachate occurred at 12 day after the initial the experimental, while the carbon dioxide methane content increased gradually and remained constant until final phase. The nitrogen production by biological denitrification of the feed nitrate increased rapidly after the reactor start up, thereafter than the nitrogen content remained constant until the end. In this study, the reactors generated 20% of hydrogen approximately, and no production of hydrogen was observed in the stable phase.

3.4. General results

The final values of the different analytical parameters of each reactor (FW, SH-OFMSW and OFMSW) measured in the experiments are presented in Table 2. The FW reactor had an average of approximately 138.0 g/kg of VS concentration, which was significantly higher than 37.0 g/kg and 22.6 g/kg of SH-OFMSW and OFMSW reactors, respectively. These supposed 32.4%, 73.7%, and 79.5% VS removal respectively.

Also, as can seen in Table 2, COD final levels (mg/kg) were significantly higher in FW reactor (48.8 mg/kg), while SH-OFMSW and OFMSW reactors showed 21.6 and 21.3 mg/kg respectively. These supposed 56.5%, 73.3%, and 74.4% of DOC removal, respectively.

Hence, OFMSW without shredded from Las Calandrias Treatment Plant showed the best performance. Therefore, the structure of the material to digest favours the biodegradation process.

Therefore, the performance results of the thermophilic anaerobic digestion of FW, SH-OFMSW and OFMSW suggest that mesophilic sludge from a stable sewage sludge digester is an adequate inoculum source due to favour a balanceable microbial population.

Table 3 show the synthesis of the performance results of three digesters. SH-OFMSW and OFMSW reactors had an average of approximately 70% of organic matter removal (calculated as TS, VS, TSS, TVS, COD and DOC), which is significantly higher than FW reactor (approximately 40%). In contrast, methane production yield of FW was significantly higher than OFMSW reactor, after 90 days. Also, the FW reactor showed higher biogas and methane production as well as accumulate of methane.

Therefore, the results obtained shows different organic digestion behaviours for FW and OFMSW wastes: (1) FW food waste showed the stable phase between 2 and 6 weeks characterized with smaller waste biodegradation and higher methane production; (2) SH-OFMSW municipal solid waste showed a stable phase between 1 and 6 weeks with higher waste biodegradation and smaller methane production.

4. Conclusion

Experimental results showed important different behaviours from organic matter biodegradation and biogas and methane production. The finals results suggest different behaviour patterns in these wastes related with the organic matter biodegradation and biogas and methane production. The FW reactor showed the smallest waste biodegradation in the stable phase (32.4% VS removal) with high methane production (4045.2 mL CH_4 cumulative). This supposes methane yield of 0.18 L CH_4/g VS; in contrast the SH-OFMSW showed higher waste biodegradation (73.7% VS removal) with small methane production (2330.0 mL CH_4 cumulative), after 90 days. In this case, the methane yield was 0.05 L CH_4/g VS. Finally, OFMSW showed the highest VS removal (79.5%) and similar values of DOC removals (74.4%). The methane yield reached 0.08 L CH_4/g VS.

Therefore, the nature of organic substrate has an important influence on the biodegradation process and methane yield. Pre-treatment of waste is not necessary for OFMSW (the structure of this waste favour the biodegradation process).

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