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Effect of substrate concentration on dry mesophilic anaerobic digestion of organic fraction of municipal solid waste (OFMSW)

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Abstract

The influence of total solid contents during anaerobic mesophilic treatment of the organic fraction of municipal solid waste (MSW) has been studied in this work. The work was performed in batch reactors of 1.7 L capacity, during a period of 85–95 days. Two different organic substrate concentrations were studied: 931.1 mgDOC/L (20% TS) and 1423.4 mgDOC/L (30% TS). Experimental results showed that the reactor with 20% total solids content had significantly higher performance. Thus, the startup phase ended at 14 days and the total DOC removal was 67.53%. The startup in reactor R30 ended at 28 days obtaining 49.18% DOC removal. Also, the initial substrate concentration contributed substantially to the amount of methane in the biogas. Hence, the total methane production in the methanogenic phase was 7.01 L and 5.53 L at the end of the experiments for R20 and R30, respectively.

Keywords: Anaerobic digestion; Organic fraction of municipal solid waste (OFMSW); Mesophilic; Biogas; Methane

1. Introduction

The production of municipal solid waste in Spain has increased from 18,783,442 (year 1998) to 24,163,199 tons (year 2003), that which supposes an increment of 28.64% in this period (INE, 2006). Of these, 40–45% corresponds to the fraction of organic, it is known as OFMSW (organic fraction of municipal solid waste). This OFMSW is susceptible of energy appraisement by the application of biological treatments.

The anaerobic digestion has been considered as the main commercial option for the treatment of the OFMSW. It produces methane and generates a digested residue that is similar to the compost produced aerobically. The process is conditioned by initial performance parameters such as: the feeding regime, the total solid contents in OFMSW, the solids retention time (SRT) and the temperature. The microorganisms are classified according to the good range of temperature in which they are developed (Romero et al., 1993; Angenent et al., 2002): psicrophilic ($T < 15$ °C), mesophilic (15 °C $< T <$ 45 °C) and thermophilic ($T >$ 45 °C). The operation in mesophilic range (33–37 °C) is more stable and requires a smaller energy expense. Also, the inhibition for ammonium (Angelidaki and Ahring, 1994; Hansen et al., 1998) and for volatile acids of long chain (Fields, 2001) is more unusual.

The methane production – and the methane yield – can be used to evaluate the anaerobic digestion of OFMWS (de Baere, 2000). In addition, methane yield can be compared with the theoretical methane yield based on the composition of the waste. The methane yield from anaerobic digestion of OFMSW has been studied in recent years (Gunaseelan, 1997; Forster-Carneiro et al., 2004, 2007a, 2007b). Actual researches on anaerobic digestion report that substantial differences are observed in the methane yields and kinetics depending on the food waste or MSW type (Forster-Carneiro et al., 2004; Rao and Singh, 2004). However, few reports can be found on the study of dry anaerobic digestion of food waste, and the explanation of

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solid wastes anaerobic digestion performance in the start-up period from the point of view of the total solids content is not extensively investigated yet.

In this work, the effect of substrate concentration (based on the total solids contents in the reactor) on the mesophilic anaerobic digestion is analyzed in the startup phase. Also, the biogas generation (methane yield) was analyzed.

2. Methods

The experimental assays were performed using separately collected OFMSW from "Las Calandrias" treatment plant located in Jerez de la Frontera (Spain). The mesophilic sludge was selected coming from a waste water treatment plant located in Jerez de la Frontera (Spain). In the previous works, the mesophilic sludge showed to be an appropriate inoculum for anaerobic digestion of food waste (Álvarez Gallego, 2005; Forster-Carneiro et al., 2007a).

2.1. Experimental reactors

The system was conformed by four reactors. The assays were carried out in batch discontinuous reactors with an internal diameter of 12.2 cm and a height of 16.5 cm. The total volume capacity was 1.7 L (laboratory scale). Each reactor had independent agitation system and electric control. The main axis contained 11 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 35 °C, controlled and monitored by means of thermostatic bath model SELECT CORP.

The conditions selected were dry anaerobic digestion (with 20% and 30% TS) at single phase mesophilic (35 °C) condition.

2.2. Characteristics of wastes and inoculums

The physical–chemical characteristics of OFMSW and mesophilic sludge are shown in Table 1.

The solid percentage of OFMSW coming from industrial treatment plant was 57.17% (high humidity degree) and the maximum original size of particles of OFMSW was 30 mm. For lab-scale studies, a previous stage of size reduction was required to increase the specific surface and to obtain more homogeneous samples. Hence, pretreatment of OFMSW, consisting in drying, crushing and shredding until obtaining particle sizes of 10 mm approx., was required to provide a suitable refined digested material, reaching 82.34% initial total solids in the samples.

Later, mesophilic inoculum with 3.64% of TS was added. Finally, water was added to fit the initial total solid contents specified in both digesters: 20% and 30% TS.

Table 1
Main physical–chemical characteristics of substrates and initial mixtures of the reactors

	OFMSW	Sludge	Mixture 20%	Mixture 30%
pH	6.51	7.49	6.68	6.46
Density (g/L)	0.666	0.971	1.035	1.130
Alkalinity ($mgCaCO_3/L$)	14.0	8.2	9.2	12.4
DOC (mg/L)	371.62	56.32	931.1	1423.4
TS (%)	82.34	3.64	16.61	27.87
VS (%)	29.89	1.85	7.03	10.12

2.3. Experimental procedure

The study is programmed to evaluate the mesophilic digestion of OFMSW at two different initial substrate concentrations in the process (coinciding with different total solids concentration): 931.1 mgDOC/L (R20: 20%TS) and 1423.4 mgDOC/L (R30: 30%TS). Four reactors were used (rehearsals for copy) of 2 L total volume and 1.7 L useful volume at discontinuous condition, inoculated with 30% (in volume) of mesophilic digested sludge. The characteristics of the initial mixtures are shown in Table 1.

2.4. Analytical methods

Every 2 days, representative samples of anaerobic digester effluents were taken. The parameters analyzed three times a week were: pH, total solids (TS), volatile solids (VS), alkalinity, volatile fatty acid (VFA) and dissolved organic carbon (DOC). Daily biogas volume and composition ($\%H_2$; $\%O_2$; $\%N_2$; $\%CO_2$ and $\%CH_4$) were analyzed. All analytical determinations were performed according to "Standard Methods" (APHA, 1995), after drying, grinding and dilution of the samples. This procedure is more representative due to the semi-solid characteristic of the substrate (except for TS and VS that is not necessary to dilute the samples) (Guitian Ojea and Carballas, 1968).

The dissolved organic carbon analysis was carried out in a SHIMADZU 5050 DOC Analyzer, by combustion-infrared method (5310B) of "Standard Methods". TS and VS analysis were realized as 2540-B method described in APHA (1995): TS samples were dried in an oven at 105–110 °C, and for VS to the dried ash waste in a furnace at 550 ± 5 °C. 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 Tedlar bag. The volume of gas produced in the reactor was directly measured using a high precision flow gas meter – WET DRUM TG 0.1 (mbar) – Ritter. – through a bag Tedlar (SKC serie 232). 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 3.0 m length) and thermal conductivity detector (TCD). The injected sample volume was 1 cm^3 and the operational conditions were as follows: 7 min at 55 °C; ramped at 40 °C min^{-1} until 150 °C. Constant temperature during