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Extraction of soluble substances from organic solid municipal waste to increase methane production

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HIGHLIGHTS

- Using water, consecutive volatile solids extractions from OFMSW were performed.
- Total and volatile solids and COD were evaluated as function of dilution and time.
- Extracts and bagasses were used for BMP tests at 35 °C during 21 days.
- Volatile solids and methane production increases with dilution rate.
- Extracting volatile solids, the methane production increases up to 47%.

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ABSTRACT

This work deals with the analysis of the methane production from Mexico City's urban organic wastes after separating soluble from suspended substances. Water was used to extract soluble substances under three different water to waste ratios and after three extraction procedures. Methane production was measured at 35 °C during 21 days using a commercial methane potential testing device. Results indicate that volatile solids extraction increases with dilution rate to a maximum of 40% at 20 °C and to 43% at 93 °C. The extracts methane production increases with the dilution rate as a result of enhanced dissolved solids extraction. The combined (extract and bagasse) methane production reached, in 6 days, 66% of the total methane produced in 21 days. The highest methane production rates were measured during the first six days.

1. Introduction

As an alternative for organic solid waste treatment, anaerobic digestion is commonly used for energy recovery in the form of methane; it allows also the reduction of waste volume to be disposed in landfills and the destruction of pathogenic organisms (Sonakya et al., 2001). There are several commercial processes, such as BTA (BTA International GmbH, 85276 Pfaffenhofen, Germany), DRANCO (OWS nv, 9000 Gent, Belgium) and Valorga (Valorga International S.A.S., 34935 Montpellier, France), among others, for biogas generation from organic solid wastes and, in the last 20 years, more than 184 commercial plants have been installed (de Baere et al., 2010). According to solids content in the reactor, anaerobic digestion technologies can be classified as *dry* and *wet* processes (de Baere et al., 2010). Due to the complexity of the organic fraction of municipal solid waste (OFMSW), the reaction times range from 15 to 30 days. Shorter reaction times are common in wet digestion with solids content between 10% and 15%.

Biogas production potential largely depends on the substrate characteristics, its biodegradability and content of carbohydrates, proteins and lipids, as well as the fractions of cellulose, hemicellulose and lignin in its composition (Hartmann and Ahring, 2006). Lignin content in OFMSW is a negative indicator of degradation (Buffiere et al., 2006). Water leaching allows the extraction of soluble organic compounds from OFMSW which are, compared to the lignocellulosic substances, readily available for the microorganisms during anaerobic digestion.

Nayono et al. (2010) and Fantozzi and Buratti (2011), using a press to "squeeze" the fresh OFMSW. They used the leachate to produce biogas and conclude that the highest biogas production was obtained during the first 5 days of the test. Unfortunately, they do not present OFMSW characterization.

When the substrate is provided to the microorganisms in dissolved form, the time required for anaerobic degradation is 3 to

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5 days, with a biogas yield similar to the untreated OFMSW. Extracting the soluble substances from OFMSW (resulting in leachate and bagasse), it is possible to obtain the same amount of biogas in less time than with wet or dry conventional technologies (Campuzano and González-Martínez, 2012). The aim of this study was to analyse the methane production from OFMSW water extractions and from the resulting bagasse and to compare the results with the methane production from Mexico City's standard OFMSW.

2. Methods

2.1. OFMSW characterization

The organic waste sample was collected from the waste truck before initiating the composting process. From approximately 500 kg, 125 kg were hand selected to exclude non-organic contaminants. The whole sample was thoroughly mixed. While the sample was still fresh, grinding was made using an electrical plate-grinding machine in order to obtain particles with sizes between 100 and 150 μm. Grinding provided additional homogenization of the sample. Samples were divided in "portions" of approximately 1 kg and stored in plastic bags at −20 °C. Determinations of total (TS), volatile (VS) and fixed (FS) solids were made; also determinations of COD, total phosphorus (TP) Kjeldahl nitrogen (KN), total carbohydrate, total protein, grease and oils, and raw fibres (lignocelluloses) were made.

2.2. Extraction of soluble compounds

Three extractions were made combining the sample OFMSW with water at three different waste to water proportions: 1:1, 1:2, and 1:3. Stirring in an orbital stirrer at 250 RPM, samples were taken for analysis at 0.25, 15, 30, 45, 60, 90, and 120 min; TS, VS and COD were determined. After 120 min duration, the remaining mixture from every flask was placed in a centrifuge to separate solids from dissolved substances and the solids were mixed again with water in the same proportions as previously described. This procedure was repeated two times to achieve three "extraction procedures".

2.3. Biochemical methane potential test

Biochemical methane potential (BMP) test of the different samples were made using the automatic methane potential test (AMPT) device from Bioprocess Control (Bioprocess Control AB, 22363 Lund, Sweden). This device consists of a constant temperature (35 °C) bath for 15 flasks, the corresponding stirring motors and the biogas measurement component coupled to a computer for continuous biogas production monitoring. The flasks are 500 mL in volume and the net volume is 400 mL. In every flask, 8 gVS anaerobic sludge was placed together with the samples: 100 mL from every extraction were used as sample and, for the raw organic waste and bagasse from the extractions, 2 gVS were used as reference. The flasks were filled with a phosphate buffer solution to 400 mL. Gas samples were taken daily and analysed using a gas chromatograph. VDI 4360 guidelines were used as reference for the BMP test.

2.4. Inoculum and nutrient requirements

The anaerobic sludge was collected from an UASB reactor from a large beer factory in Mexico City. The granules were placed in a mixer to obtain a homogeneous sludge. The inoculum was then analysed for total and volatile solids in order to include 8 gVS in each flask. In every flask, 1 mL of micronutrients solution was added; chemicals and their concentrations in mg/L were $FeCl_3{\cdot}4H_2O$, 2000; $MnCl{\cdot}4H_2O$, 2000; $ZnCl_2$, 500; $CoCl_2{\cdot}6H_2O$, 30; $CuCl_2{\cdot}2H_2O$, 50; H_3BO_3, 50; $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$, 90; $NiCl_2{\cdot}6H_2O$, 50; EDTA, 1000; HCl, 1.

2.5. Analytical methods

Humidity, TS, VS, FS, KN, TP and COD were determined according to Standard Methods (APHA, 2005). Raw fibres, lignin, hemicellulose and cellulose were determined with acid-detergent fibre (ADF) method, neutral detergent fibre (NDF) method and H_2SO_4 lignin according to the Association of Official Analytical Chemists (AOAC, 2012). Total proteins were calculated multiplying organic nitrogen by 6.25 (Cabbai et al., 2013). Carbohydrates were determined according to the Dubois method (Dubois et al., 1956). Grease and oils were determined with ether in a Soxhlet device. Values of pH were measured at beginning and end of every test with a Thermo Scientific Orion 2 Star pH meter.

Biogas composition was determined using a gas chromatograph (SRI 8610c) equipped with thermal conductivity detector (TCD) and stainless steel silica gel packed column 8600-PK1A using helium gas as carrier at a flow rate of 27 mL/min. The injected sample was 0.5 mL and the operating conditions were: 1 min at 50 °C, ramped at 50 °C/min to 100 °C and maintained per 1 min. Detector temperature is 150 °C. All results of the methane production are presented in standard conditions (0 °C and 1 atm).

2.6. Statistical analysis

Statistical analysis was made with PASW Statistics 18. One way ANOVA and Tukey analysis was used to determine significance differences from the average values of TS, VS and COD with respect to time and to the water volume used in the tests. Significance level 0.05 was set for the analysis.

3. Results and discussion

3.1. OFMSW characteristics

The main characteristics in (g/kg) of the wastes used are: Chemical oxygen demand (COD) = 304 ± 11.2, total solids (TS) = 297 ± 4.2, volatile solids (VS) = 223 ± 4.2, fixed solids (FS) = 75 ± 0.5, carbohydrates = 118 ± 7.0, raw fibres = 88 ± 0.4, grease and oils = 39 ± 3.9, protein = 34 ± 0.8, lignin = 30 ± 2.0, cellulose = 47 ± 1.9, hemicellulose = 12 ± 0.25, Kjeldahl nitrogen (KN) = 5.4 ± 0.1, and total phosphorus (TP) = 1.8 ± 0.05.

OFMSW contains 29.7% TS and 69.3% humidity. Organic matter, as VS, contains 53% carbohydrates, 17% grease and oils, 15% is protein and 13% is lignin. According to Buffiere et al. (2006) lignin is not degradable during anaerobic digestion. VS/TS ratio is 0.75 but, considering that 13% of VS is lignin, then the VS_{bio}/TS ratio is 0.65. The biodegradable fraction of VS, VS_{bio}, is the total VS minus the lignin contents; then VS_{bio} is 193 g/kg.

The general characteristics of Mexico City's OFMSW are similar to organic solid wastes from other countries. Table 1 shows a comparison of the OFMSW characteristics reported in several papers. With the exception of Fantozzi and Buratti (2011) and Forster-Carneiro et al. (2008b), TS have values between 277 and 309 g/kg (wet basis). The values of VS/TS reported are from 0.77 to 0.95, without considering the values reported by Forster-Carneiro et al. (2008b); they report a lower value of 0.43. The VS/TS ratio of Mexico City's OFMSW presents a value of 0.75. Important differences are observed in macronutrients: KN presents values between 5.3 and 28 g/kg and 0.63 to 2.4 g/kg for TP. Mexico City's OFMSW