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Biogas Production from Solid State Anaerobic Digestion for Municipal Solid Waste

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Municipal solid wastes (MSW) were used as feedstock to produce biogas by anaerobic digestion. Experiments were carried out in batch stirred reactors using different amounts of inoculum under mesophilic conditions (37 °C). The effect of the inoculum amount on the biogas cumulative volume and composition was investigated. The profiles of pH, volatile acids were also taken into account to explain the effect of the inoculum amount, to find the optimal conditions for the reactor.
Higher amounts of inoculum resulted in higher concentrations of VFA, causing a reduction of the biogas yield. The maximum specific biogas production was obtained using the minimum amount of inoculums. The experimental results gave indications about the measures to be adopted to optimize the anaerobic digestion of the MSW.

1. Introduction

The increasing worldwide industrialization and urbanization have significantly increased the amount of wastes generated from Municipal Solid Wastes (MSW). If these wastes are not properly managed, they may pose a severe threat to the health status of humans. Anaerobic Digestion (AD) processes could offer an efficient management strategy to exploit the organic fraction of MSW (Cuetos et al., 2008; Fernandez et al., 2008; Liu et al., 2008; Macias-Corral et al., 2008; Lee et al., 2009).
Biogas is an alternative source of energy that can be used in different applications (Roubaud et al., 2005). It can be compressed to be used as a source of car fuel similar to that of compressed natural gas (CNG). Alternatively, it can be burned to generate heat or electricity, or liquefied to produce methanol. It can also be used as feedstock for the catalytic steam methane reforming (SMR). Refined biogas can be fed into gas distribution grids, or used to feed fuel cells.
If the organic component of the solid waste is rehabilitated into energy by anaerobic digestion, it will decrease the adverse effect on the environment and contribute to reduction in consumption of fossil fuel.
The aim of the present work is to optimize the inoculum concentrations on the AD of MSW under mesophilic conditions (37°C). The profiles of different intermediate and final products are discussed in order to explain the observed behavior of the AD reactor.

2. Materials and methods

2.1 Materials

The composition of MSW varies from region to region and depends upon the lifestyle, demographic features and legislation. In this study we used a synthetic MSW having the composition shown in Table 1 (Krishna et al., 2009), adding a volume of deionized water equal to 24% of MSW total weight.

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The inocula for AD tests were obtained from a primary sludge digester of a municipal wastewater treatment plant located in Nola (Italy). The anaerobic consortium was adapted to a synthetic medium containing glucose (10 g/L) as carbon source, Na_2HPO_4 (7.0 g/L), KH_2PO_4 (3.0 g/L), NaCl (0.5 g/L), NH_4Cl (1.0 g/L) and trace elements. Resazurin (0.025% v/w) was added as anaerobiosis indicator (Toscano et al., 2013).

2.2 Batch experiments

Crimped pyrex bottles with perforable butyl rubber septa, with a working volume of 100 mL, were used as batch reactors. The reactors were filled with MSW, inoculated with different volumes (10, 15, and 20 mL) of inoculum, then distilled water was added to obtain a total liquid volume of 100 mL. Anaerobic conditions were ensured by sparging the medium with nitrogen for 20 min, after that the reactors were placed in an incubator (Infors HT Minitron) at 37°C and 150 rpm for 192 hours.
Each reactor was connected to an upturned bottle (125 mL) entirely filled with distilled water (Figure 1) by a capillary tube, equipped on both ends with a needle. The biogas volume was determined measuring the water displaced through a needle from the upturned glass bottle.

Table 1 – Composition of the synthetic MSW

Garden waste	20%
Vegetable waste	10%
Cooked meet	5%
Cellulose (not paper)	5%
Paper	20%

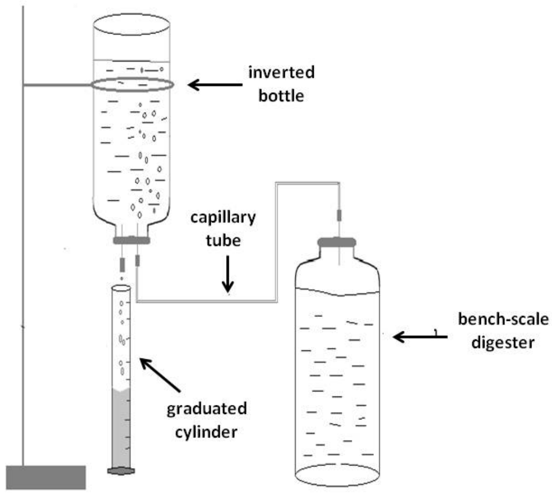

Figure 1 - Experimental apparatus for anaerobic fermentation process and biogas measurement.

2.3 Other analytical methods

The biomass composition was monitored by measuring optical absorbance of liquid samples at 600 nm.
The liquid samples were centrifuged, filtered (0.2 μm cut-off filters) and analyzed for residual substrates (glucose or total reducing sugars) and soluble fermentation products (organic acids, alcohols).
The concentration of glucose was measured following a modified Nelson-Somogyi method for reducing sugars (Pirozzi et al., 2013).

The concentration of volatile acids (acetic acid, butyric acid, propionic acid) and ethanol was determined by gas-chromatograph analysis, using a Shimadzu GC-17A equipped with a FID detector and a capillary column with a PEG stationary phase (BP20, 30 m by 0.32 mm i.d., 0.25 μm film thickness, from SGE).
Biogas (H2, CO2, and CH4) composition was obtained using a HP 5890 (GC) equipped with a TCD detector and a molecular sieve wide bore capillary column.
The pH was measured using 740 pHmeter (WTW, Germany). TS and VS were measured by standard methods 2540B, 2540E (APHA, 2005).

3. Results and discussion

3.1 VF and pH variations during the anaerobic digestion

In the Figure 2 the acetic, butyric and propionic acid and the ethanol profiles are showed as a function of time for the three different concentrations of inoculum. The production of ethanol, acetic acid and butyric acid indicates that acetic and butyric fermentations are ongoing, causing a reduction of the biogas yield. The high values of the final concentration of butyric acid contribute to inhibit the bacteria that are responsible of the subsequent stages of the process. The sample obtained using an higher amount of inoculum resulted in higher concentrations of VFA.
The pH variations during the digestion period are shown in the Figure 3. When pH<6, a 1 M Na_2HCO_3 solution was added into the reactor to avoid the inhibition of methanogenesis occurring under acidic conditions. Nevertheless, a decreasing behavior of the pH was observed in each test. The pH profiles observed in each test was corresponding to the profiles of the VFA concentration.

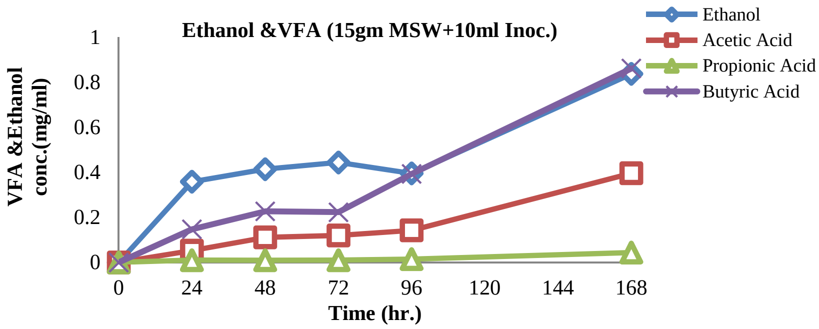

Figure 2a - VFA variation during digestion at 37°C, 150 rpm. Inoculum: 10 ml. Products: Ethanol (◊),Acetic Acid (□), Propionic Acid (Δ) and Butyric Acid (x).

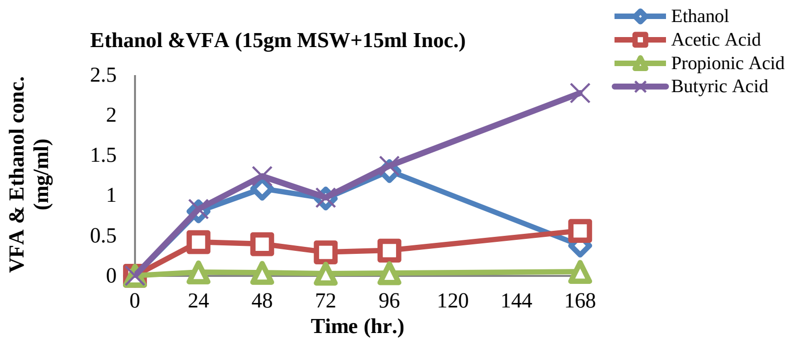

Figure 2b - VFA variation during digestion at 37°C, 150 rpm. Inoculum: 15 ml. Products: Ethanol (◊),Acetic Acid (□), Propionic Acid (Δ) and Butyric Acid (x).

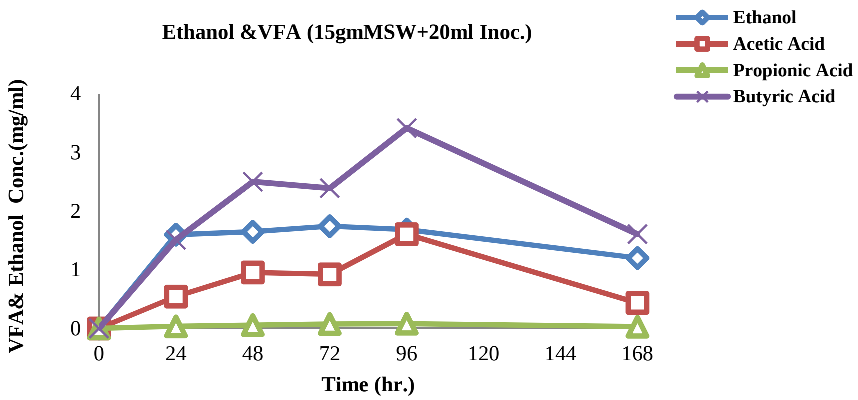

Figure 2c - VFA variation during digestion at 37ºC, 150 rpm. Inoculum: 20 ml. Products: Ethanol (◊),Acetic Acid (□), Propionic Acid (Δ) and Butyric Acid (x).

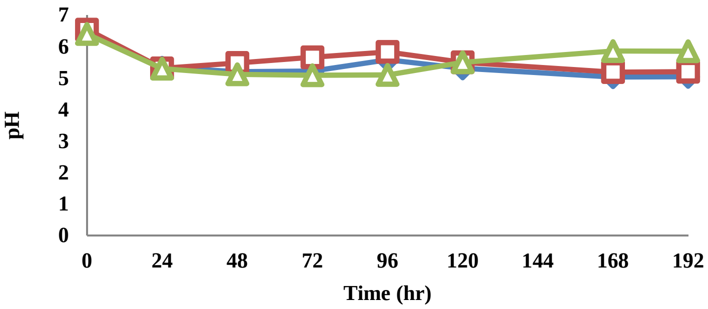

Figure 3 - pH variation during AD tests at 37ºC, 150 rpm. Volumes of inoculum: 10 ml (◊), 15 ml (□), 20 ml (Δ).

3.2 Biogas yield

The cumulative volumes of biogas per VS added (specific biogas production) are presented in the Figure 4. The maximum specific biogas production was obtained using the minimum amount of inoculum (10ml).
In order to explain this result, we measured the concentration-time profiles of biogas (CH_4, H_2 and CO_2) at different volumes of inoculum (10, 15, 20 ml). The results, shown in the Figures 5a-b-c, demonstrate that higher fraction of methane are obtained as the inoculum volume is lower. The maximum heating value measured for the produced biogas was 21,2 MJ/m^3. Consequently, it can be said that higher volumes of inoculums cannot represent the best choice, as they produce higher production of VFA, and then higher inhibition effects.

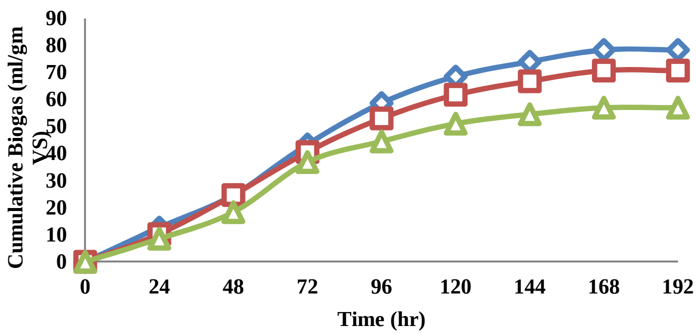

Fig. 4 - Cumulative biogas/g VS yield during AD tests at 37ºC, 150 rpm Volumes of inoculum: 10 ml (◊), 15 ml (□), 20 ml (Δ)

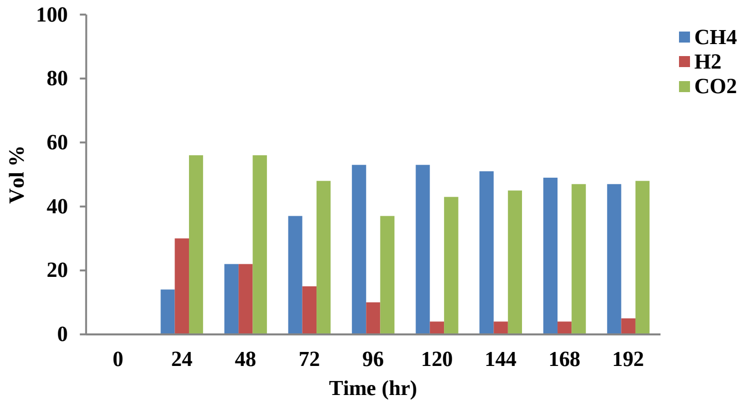

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Figure 5a. Biogas composition during digestion at 37°C, 150 rpm. Inoculum: 10 ml.

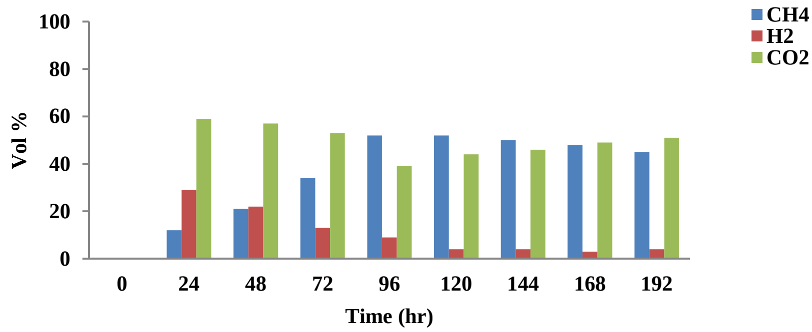

Figure 5b. Biogas composition during digestion at 37°C, 150 rpm. Inoculum: 15 ml.

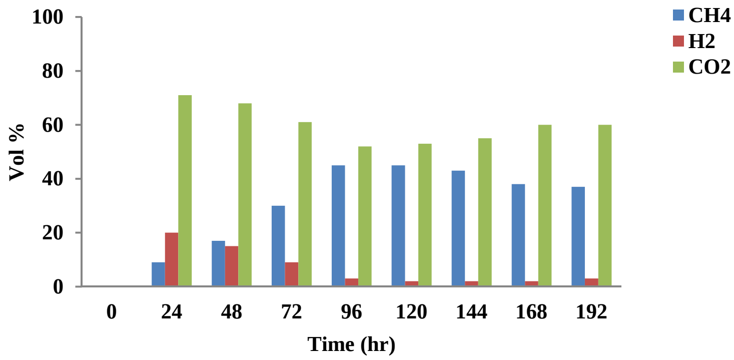

Figure 5c. Biogas composition during digestion at 37°C, 150 rpm. Inoculum: 20 ml.

4. Conclusions

The experimental work was devoted to optimize the biogas production from synthetic MSW. In particular, the effect of the inoculum amount was characterized to minimize the generation of inhibitors of the bacterial growth. The biogas production was measured together with intermediate products of AD (acetic acid, butyric acid, propionic acid and ethanol). The biogas composition was analysed in terms of CH_4, H_2 and CO_2.
The experimental results showed that, in some instances, a minimum inoculum volume is to be preferred. In order to obtain a further optimization of the process, a selective pressure against methanogens is to be provided.
The future work will be devoted to achieve a complete optimization of the system, with reference to different possible applications of the AD.

In particular, AD will be used to exploit the wastewaters obtained from the Fisher-Tropsch conversion of syngas. These wastewaters typically contain a mixture of alcohols of different chain lengths (from methanol to decanol), and consequently require the adoption of specific operation conditions.
The conditions of the process will also be adapted taking into account the possible uses (already mentioned in the Introduction) of the produced biogas. In this view, specific methods will be developed to clean biogas from impurities such as H_2S and CO_2 that may act as poisons for catalysts to be used in subsequent processes (i.e. fuel cells).

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