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Biochemical methane potential tests of different autoclaved and microwaved lignocellulosic organic fractions of municipal solid waste

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ABSTRACT

The aim of this research was to enhance the anaerobic biodegradability and methane production of two synthetic Organic Fractions of Municipal Solid Waste with different lignocellulosic contents by assessing microwave and autoclave pre-treatments. Biochemical Methane Potential assays were performed for 21 days. Changes in the soluble fractions of the organic matter (measured by soluble chemical oxygen demand, carbohydrates and proteins), the first order hydrolysis constant k_h and the cumulated methane production at 21 days were used to evaluate the efficiency of microwaving and autoclaving pretreatments on substrates solubilization and anaerobic digestion. Microwave treatment led to a methane production increase of 8.5% for both the tested organic fractions while autoclave treatment had an increase ranging from 1.0% to 4.4%. Results showed an increase of the soluble fraction after pre-treatments for both the synthetic organic fractions. Soluble chemical oxygen demand observed significant increases for pretreated substrates (up to 219.8%). In this regard, the mediocre results of methane's production led to the conclusion that autoclaving and microwaving resulted in the hydrolysis of a significant fraction of non-biodegradable organic substances recalcitrant to anaerobic digestion.

1. Introduction

Anaerobic digestion (AD) is an efficient organic waste treatment that has gained interest during the last years as it recovers energy in the form of biogas for use in combined heat and power plants. Nowadays the scientific and technical community is focused in drawing new borders for the development of the process with particular regard to the study of the dark fermentation and the production of biohydrogen (Alibardi and Cossu, 2015; Cappai et al., 2014; De Gioannis et al., 2013) and the application of pretreatments to enhance methane production from lignocellulosic and non-lignocellulosic substrates (Ariunbaatar et al., 2014a; Cesaro and Belgiorno, 2014).

The Organic Fraction of Municipal Solid Wastes (OFMSW) contains a high content of lignocellulosic fiber that is not readily digestible. Alibardi and Cossu (2015) studied OFMSW composition investigating five fractions (on weight basis, % w/w): meat-fish-cheese (0.3–12%); fruit (12.7–24.8%); vegetables (18.2–42.3%); pasta-bread (1.3–12.3%); undersieve (13.0–17.5%); rejected materials as paper and cardboard, kernels, etc (17.0–22.2%). This latter category and yard waste are typical lignocellulosic fractions which are significant parts in Tuscan OFMSW (Pecorini et al., 2013). For instance, wood fiber of yard waste typically comprises around 25–30% hemicellulose and 45% cellulose, on a dry weight basis (Pérez et al., 2002). The encasing of cellulose and hemicelluloses in lignin may considerably restrict anaerobic degradation in which the limiting factor is the hydrolytic phase due to constrained accessibility of particulate substrates by enzymes and/or the complexity of compounds that need to be hydrolyzed (Delgènes et al., 2003). The rupture of the complex structure is essential for enzymatic attack and efficient bioconversion to processes such as hydrolysis, fermentation and biomethanogenesis. Pretreatments of OFMSW to enhance hydrolysis can be used to solubilize organic matter prior to AD in order to improve the overall AD process in terms of faster rates and degree of OFMSW degradation, thus increasing methane production (Cesaro and Belgiorno, 2014; Shahriari et al., 2012).

Abbreviations: A, autoclave; AD, anaerobic digestion; BMP, biochemical methane potential; COD, chemical oxygen demand; EB, energy produced in form of biogas; ED, energy demand; EQ, energy recovered in form of heat; ET, energy profit of the pretreatment; GS, gas production sum; MW, microwave; OFMSW, organic fraction of municipal solid waste; sCarb, soluble carbohydrates; sCOD, soluble chemical oxygen demand; SD, standard deviation; sProt, soluble proteins; TS, total solids; TVS, total volatile solids.

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Moreover, substrate pre-treatments have been shown to be a useful step to enhance aerobic biodegradation processes as composting (Ibrahim et al., 2011) and for pathogens destruction (Ariunbaatar et al., 2014a).

Several methods have been assessed for their technical feasibility at pre-treating residues. These include enzymatic (Bru et al., 2012), chemical (Dewil et al., 2007), ultrasonic (Cesaro et al., 2014), thermal (Ariunbaatar et al., 2014b; Li and Jin, 2015; Wang et al., 2010), hydrothermal (Lissens et al., 2004; Tampio et al., 2014) and microwave (Marin et al., 2010; Shahriari et al., 2012) treatments. The present research focuses its attention on these latter methods in order to study the anaerobic biodegradability and methane production of two different OFMSW by assessing Autoclaving (A) and Microwaving (MW). The two methods were tested since the former is able to release the cellulosic materials enmeshed in lignin resulting in an increase of smaller molecules available for further processing (Heerah et al., 2008; Papadimitriou, 2010) while the latter is an optimal method to solubilize organic solids and as such is a suitable candidate to treat OFMSW (Shahriari et al., 2013).

Autoclaving is a hydrothermal treatment where water is used as a reagent at increased temperature and pressure to hydrolyze and solubilize sugars, starch, proteins and hemicelluloses (Tampio et al., 2014). Autoclaving involves the high pressure sterilization of waste by steam which cooks the waste and destroys any bacteria in it (Ibrahim et al., 2011). The main factors influencing the process are temperature, pressure and time. Several studies investigated the effect of these process parameters by studying lighter and more aggressive treatment conditions. Time and temperature depend on the volume of waste feed into autoclave usually ranging between 120 and 160 °C within 1 h (Ibrahim et al., 2011). Marchesi et al. (2013) studied the biochemical methane potential (BMP) of organic waste after autoclaving for 15–30 min at 2 bars and 134 °C while Heerah et al. (2008) autoclaved lignocellulosic biomass at 95 °C and 1 bar for four consecutive cycles each lasting 45 min. Papadimitriou (2010) autoclaved commingled household waste for 1 h at 200 °C and 15.5 bars, Tampio et al. (2014) treated source segregated food waste at 160 °C and 6.2 bars and Wilson and Novak (2009) studied secondary sludge at 220 °C and 28.7 bars for 2 h. Most of the detected results showed an increase in soluble COD (Heerah et al., 2008; Marchesi et al., 2013; Papadimitriou, 2010) and an increase in methane production (Heerah et al., 2008; Lissens et al., 2004). Bougrier et al. (2008) and Tampio et al. (2014) reported that more aggressive thermal and hydrothermal pre-treatments at higher temperatures (around 180 °C) decrease biodegradability and biogas production. This is attributable to the formation of complex and inhibitory Maillard compounds, produced by reactions between amino acids and carbohydrates. Another possible drawback of the treatment is the release of a high total ammonia nitrogen load due to protein solubilization (Wilson and Novak, 2009) that could induce a methanogenic inhibition.

Microwave irradiation is an electromagnetic radiation with a wavelength between 0.001 and 1 m, corresponding to an oscillation frequency of 300–0.3 GHz (Appels et al., 2013; Eskicioglu et al., 2007). Domestic "kitchen" microwave ovens and industrial microwave generators are generally operating at a frequency of 2.45 GHz with a corresponding wavelength of 0.12 m and energy of $1.02 \cdot 10^{-5}$ eV (Appels et al., 2013; Beszédes et al., 2008). MW is an alternative method to conventional thermal pre-treatments as it is able to break organic molecules. The cell liquor and extracellular organic matter within polymeric network can release into the soluble phase increasing the ratio of accessible and biodegradable component. This effect could be manifested by different ratio of soluble and total COD and the increased rate of biogas production (Beszédes et al., 2008). The main factors influencing the treatment are temperature, power and irradiation time. Literature reports a range of application of the power between 440 and 500 W (Elagroudy and El-Gohary, 2013; Rani et al., 2013; Sólyom et al., 2011) and 1250 W (Coelho et al., 2011; Eskicioglu et al., 2007; Marin et al., 2010). The applied temperature covers a wide range of values: from 30 °C (Kuglarz et al., 2013) to 175 °C (Marin et al., 2010). The irradiation time is generally found to be in the order of few minutes (1–10 min) even if some works present irradiation time higher than 40 min (Marin et al., 2010; Shahriari et al., 2012). As for autoclaving, MW with high temperatures, long irradiation time and thus a significant applied energy (e.g. until 12,000 kJ/kg in Beszédes et al. (2008) and until 2333 kJ//kg in Rani et al., 2013) could lead to the formation of refractory compounds inhibiting the digestion (Marin et al., 2010; Shahriari et al., 2012).

The enhancement of methane production due to the application of pre-treatments is generally analyzed through BMP tests (Beszédes et al., 2008; Elagroudy and El-Gohary, 2013; Eskicioglu et al., 2007; Kuglarz et al., 2013; Lissens et al., 2004; Marchesi et al., 2013; Marin et al., 2010; Rani et al., 2013; Shahriari et al., 2012; Sólyom et al., 2011; Zhou et al., 2013) while the solubilization effect is usually monitored through analysis on the soluble fractions of the organic matter.

As previously mentioned, many works have already investigated the effect of pretreatments on the anaerobic digestion of several substrates. Nevertheless, it is still not clear whether these treatments are effective on lignocellulosic materials such as it might be the OFMSW. Under this perspective the present work aims at evaluating microwave and autoclave pretreatments on the anaerobic digestion of lignocellulosic OFMSW giving a first indication on which of the two methods is more suitable for a richer or for a meager lignocellulosic OFMSW. Focusing the attention on the lignocellulosic fraction of biowaste, the study was conducted by varying the lignocellulosic content of OFMSW while the pretreatment conditions were not changed. As such it has been selected a single condition for A and MW characterized by low treatment energy with the intention of limiting the energy expenses and prevent the formation of refractory compounds. The objective of this work is therefore to study the enhancement of the anaerobic biodegradability and methane production of two synthetic OFMSW with different lignocellulosic content (M1 and M2) by assessing microwave (M1_MW and M2_MW) and autoclave (M1_A and M2_A) pre-treatments. BMP assays were performed for 21 days (Cossu and Raga, 2008). Changes in the soluble fractions of the organic matter (measured by soluble COD, carbohydrates and proteins), the first order hydrolysis constant k_h and the cumulated methane production (BMP_{21}) were used to evaluate the efficiency of microwaving and autoclaving on substrates solubilization and AD process.

2. Materials and methods

2.1. Organic waste and inoculum

Two different samples of OFMSW with different lignocellulosic contents were assessed. The two samples were achieved taking into account the main fractions of Italian OFMSW (Alibardi and Cossu, 2015) and varying the different amounts in order to control proteins (meat), carbohydrates (pasta) and fibers content (fir sawdust and vegetables). Similarly to Shahriari et al. (2013), M1 sample was characterized by (% w/w): fir sawdust (10%), grass (30%), carrot (10%), cabbage (10%), spinach (10%), cooked meat (7.5%), raw meat (7.5%) and cooked pasta (15%). M2 sample was composed by (% w/w): fir sawdust (25%), grass (20%), carrot (10%), cabbage (10%), spinach (10%), cooked meat (5%), raw meat (5%) and cooked