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Anaerobic digestion of organic fraction of municipal solid waste combining two pretreatment modalities, high temperature microwave and hydrogen peroxide

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ABSTRACT

In order to enhance anaerobic digestion (AD) of the organic fraction of municipal solid waste (OFMSW), pretreatment combining two modalities, microwave (MW) heating in presence or absence of hydrogen peroxide (H_2O_2) were investigated. The main pretreatment variables affecting the characteristics of the OFMSW were temperature (T) via MW irradiation and supplemental water additions of 20% and 30% (SWA20 and SW30). Subsequently, the focus of this study was to evaluate mesophilic batch AD performance in terms of biogas production, as well as changes in the characteristics of the OFMSW post digestion. A high MW induced temperature range (115–175 °C) was applied, using sealed vessels and a bench scale MW unit equipped with temperature and pressure controls. Biochemical methane potential (BMP) tests were conducted on the whole OFMSW as well as the liquid fractions. The whole OFMSW pretreated at 115 °C and 145 °C showed 4–7% improvement in biogas production over untreated OFMSW (control). When pretreated at 175 °C, biogas production decreased due to formation of refractory compounds, inhibiting the digestion. For the liquid fraction of OFMSW, the effect of pretreatment on the cumulative biogas production (CBP) was more pronounced for SWA20 at 145 °C, with a 26% increase in biogas production after 8 days of digestion, compared to the control. When considering the increased substrate availability in the liquid fraction after MW pretreatment, a 78% improvement in biogas production vs. the control was achieved. Combining MW and H_2O_2 modalities did not have a positive impact on OFMSW stabilization and enhanced biogas production. In general, all samples pretreated with H_2O_2 displayed a long lag phase and the CBP was usually lower than MW irradiated only samples. First order rate constant was calculated.

1. Introduction

Municipal solid waste (MSW) is one of the largest sources of organic waste generated by our society. Almost 54% of the US's annual production of about 243 million tons (USEPA, 2009) is still landfilled. Similarly in 2008, Canadians produced 34 million tons of MSW of which 76% was disposed in landfills (Statistics Canada, 2008). Conventional landfilling is not sustainable and leads to production of leachate and uncontrolled greenhouse gas emissions (e.g., methane). The organic fraction of MSW (OFMSW) is a large and renewable potential energy source that can be exploited on a sustained basis if treated under controlled conditions to reduce the environmental impact and recover energy.

Anaerobic digestion (AD) under controlled conditions is one appropriate technique for treatment of OFMSW and is currently employed mostly in Europe. Low biosolids production, low energy consumption and high rates of controlled biogas production which can be considered a renewable energy source, are the main benefits of the process. AD of OFMSW can be divided into four main stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. During hydrolysis, suspended solid reactants are solublized so they can be converted into biogas by the anaerobic consortium and is the rate-limiting step for residuals containing suspended solids (Eastman and Ferguson, 1981). Concomitantly, AD of OFMSW usually requires a long retention time of more than 20 days in conventional digesters (Climent et al., 2007), with concomitant large reactor volume requirements.

Pretreatment 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 reducing AD retention time and increasing methane production (Mata-Alvarez, 2003).

Most pretreatment studies have focused on single modalities with applications to waste activated sludge (WAS). Pretreatment

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methods proposed and evaluated to enhance AD, include, mechanical disintegration, ultrasound, thermal, chemical and thermo-chemical pretreatment methods (Sawayama et al., 1997; Lissens et al., 2004; Ardic and Taner, 2005; Mshandete et al., 2006; Bougrier et al., 2007; Khanal et al., 2007; Akin, 2008; He et al., 2008). However, conventional thermal pretreatment at high temperature (160–175 °C) and pressures (6–8 bar) has been demonstrated to produce better digestion results in terms of increased volatile solids (VS) destruction as well as a surplus of energy gain due to higher biogas production (Abraham et al., 2003).

MW heating has a higher energy efficiency than conventional heating and has been evaluated at high temperature with thickened WAS (TWAS) by Toreci (2008). MW heating to 175 °C resulted in 4.5 ± 0.8 and 8.8 ± 0.9-fold increases in soluble chemical oxygen demand (SCOD) concentration for 6% and 11.8% total solids (TS) concentrations vs. controls. Additionally TWAS with 3% TS concentration pretreated to 175 °C produced 31 ± 6% more biogas by the 18th day of the mesophilic biochemical methane potential (BMP) assay compared with controls.

Zheng et al. (2009) studied the effect of MW heating on the characteristics and BMP of primary sludge (PS) which may better resemble OFMSW. The ratio of soluble to total chemical oxygen demand (SCOD/TCOD) increased almost 2.5-fold compared to controls with 4% TS and a MW pretreatment temperature of 90 °C, the BMP biogas production rate increased by 37%. They reported a 28% reduction in the digestion time to achieve 85% of the ultimate biogas production. Increased biogas production was also reported by Eskicioglu et al. (2007) for TWAS. MW heating to 96 °C resulted in 3.6 ± 0.6 and 3.2 ± 0.1-fold increases in SCOD/TCOD at 5.4% and 1.4% TS concentrations, respectively. Subsequent mesophilic BMP assays resulted in 15 ± 0.5% and 20 ± 0.3% improvements over controls after 19 days of AD.

Recent studies have shown synergic solublization effects for TWAS when MW heating is combined with the oxidizing agent H_2O_2. Wong et al. (2006) reported that MW/H_2O_2 pretreatment of TWAS converted a larger fraction of TCOD into SCOD. TCOD was completely converted into SCOD at 80 °C when 2 mL H_2O_2 (30%) was added to 30 mL TWAS (TS = 0.35–0.40%). Eskicioglu et al. (2008) conducted BMP assays on TWAS after pretreatment by MW heating in presence of H_2O_2. SCOD/TCOD ratios for MW heating alone were 3 ± 0%, 12 ± 0%, 15 ± 0%, 16 ± 0% and 15 ± 1% for control, MW-60 °C, MW-80 °C, MW-100 °C and MW-120 °C, respectively. H_2O_2 and dual modality MW-60 °C/H_2O_2, MW-80 °C/H_2O_2, MW-100 °C/H_2O_2 and MW-120 °C/H_2O_2 samples achieved 17 ± 2%, 15 ± 1%, 18 ± 0%, 21 ± 1% and 24 ± 1% SCOD/TCOD ratios, respectively, indicating a synergic effect on solubilization when H_2O_2/MW modalities were combined. However, MW/H_2O_2 pretreatment resulted in slower biodegradation rates and lower methane yields compared to control and MW heated only samples. It was not reported if the lower rates and methane yields were an acute or chronic effect of the combined pretreatment. Combined modality pretreatment of this type has not been extended to OFMSW.

Shahriari et al. (2011) studied the effect of MW on solubilization of model OFMSW (M-OFMSW). The greatest increase in waste solublization based on SCOD was achieved at 175 °C. MW pretreatment resulted in 1.61 ± 0.05, 1.62 ± 0.01 and 1.58 ± 0.03 times higher SCOD with supplemental water addition of 30% (SWA30) for temperature ramp rates of 2.5, 3.8 and 7.5 °C/min, respectively. For the same conditions, release of bound water of samples into the free liquid fraction was 1.39 ± 0.01, 1.34 ± 0.02 and 1.37 ± 0.01 times higher than control. It can be concluded that microwaving of M-OFMSW at high temperature (175 °C) provides potentially beneficial conditions for waste solubilisation and subsequent enhanced AD. The actual effect of MW pretreatment on the AD process was not determined in their experiments.

The purpose of this study is to investigate the effects of single modality and combined MW/H_2O_2 pretreatment on mesophilic AD of M-OFMSW. It is hypothesized that MW heating at high temperature and pressure when combined with H_2O_2 pretreatment will increase solubilization of organic solids, increasing bioavailability of biodegradable substrate resulting in increased rates and extent of OFMSW digestion compared with MW pretreatment only.

2. Methodology

2.1. Organic waste

Real OFMSW has variable characteristics; therefore M-OFMSW was used to minimize compositional variation. M-OFMSW composition was based on experiments by Wang et al. (2006) and Luostarinen and Rintala (2007). It had a similar composition of protein, carbohydrates, vegetables and fat as the Canada Food Guide (CFG, 2007), thus was representative of Canadian kitchen waste. M-OFMSW contained cooked rice (18 wt%), cooked pasta (18 wt%), cabbage (11 wt%), carrot (11 wt%), apple (11 wt%), banana (11 wt%), corned ground beef (10 wt%) and dog food (10 wt%). Rice and pasta was cooked for 15 min then strained prior to MW pretreatment. Moisture content of M-OFMSW was 80.7 ± 0.3%. To reduce the particle size 1 kg of M-OFMSW was placed in a Kitchen Aid food processor (PowerPro II, 500 W) for 30 s at high speed prior to any pretreatment. Additionally, supplemental tap water or H_2O_2 of 20% and 30% was added to the M-OFMSW prior to pretreatment in order to increase the water content for enhancing solubilization by MW heating. Final moisture content of supplemental water addition of 20% (SWA20) or SWA20–H_2O_2, and SWA30 or SWA30–H_2O_2 mixtures were 80.7 ± 0.3% or 84.9 ± 0.3%, and 85.7 ± 0.3% or 88.3 ± 0.4%, respectively.

2.2. Microwave pretreatment and dual modality, microwave and H_2O_2 pretreatment

A laboratory MW Accelerated Reaction System (Mars 5®) was used to pretreat the M-OFMSW. This system consists of the following:

- User selectable power settings (0–1200 W) and constant frequency of 2450 MHz.
- A programmable microcomputer that controls and monitors power delivered as well as temperature, and pressure within sealed reaction vessels.
- Explosion proof sealed reaction vessels that eliminate volatile losses and can operate up to 250 °C and 3.45 MPa.

Each reaction vessel was filled with 50 g of M-OFMSW. Samples were heated from room temperature to 115, 145 and 175 °C at a constant temperature ramp time of 40 min. Once final temperature was reached it was held for 1 min. Samples were cooled to room temperature prior to opening to minimize volatilization losses.

For dual modality pretreatment M-OFMSW was placed in a volumetric flask and H_2O_2 (30% v/v) was added slowly (0.38 and 0.66 g H_2O_2/g TS to produce SWA20–H_2O_2 and SWA30–H_2O_2, respectively). SWA20–H_2O_2 and SWA30–H_2O_2 mixtures were reacted for 1 h at room temperature. Subsequently, they underwent identical MW ramping as described above but only to a final temperature of 85 °C.

2.3. Biochemical methane potential assay

BMP assays were used to evaluate the effect of single and dual modality pretreatments on ultimate methane production (i.e.