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Enhanced anaerobic digestion of food waste by thermal and ozonation pretreatment methods

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ABSTRACT

Treatment of food waste by anaerobic digestion can lead to an energy production coupled to a reduction of the volume and greenhouse gas emissions from this waste type. According to EU Regulation EC1774/2002, food waste should be pasteurized/sterilized before or after anaerobic digestion. With respect to this regulation and also considering the slow kinetics of the anaerobic digestion process, thermal and chemical pretreatments of food waste prior to mesophilic anaerobic digestion were studied. A series of batch experiments to determine the biomethane potential of untreated as well as pretreated food waste was carried out. All tested conditions of both thermal and ozonation pretreatments resulted in an enhanced biomethane production. The kinetics of the anaerobic digestion process were, however, accelerated by thermal pretreatment at lower temperatures (<120 °C) only. The best result of 647.5 ± 10.6 mlCH_4/gVS, which is approximately 52% higher as compared to the specific biomethane production of untreated food waste, was obtained with thermal pretreatment at 80 °C for 1.5 h. On the basis of net energy calculations, the enhanced biomethane production could cover the energy requirement of the thermal pretreatment. In contrast, the enhanced biomethane production with ozonation pretreatment is insufficient to supply the required energy for the ozonator.

1. Introduction

Food waste (FW) is the largest fraction of municipal solid waste (MSW). A study by the Food and Agricultural Organization (FAO, 2011) suggests that one-third of the food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year (FAO, 2011). The generation of MSW and FW are predicted to increase with 51 and 44%, respectively, by 2025; and if the current integrated solid waste management is practised, the global methane production from landfilled FW will increase from 3 to 48 Gkg by 2025, contributing to global warming (Adhikari and Barrington, 2006). While it is important to reduce the amount of FW generated, it is also necessary to develop sustainable treatment and management schemes (Carlsson et al., 2012; Zaman, 2013). Hence, these have become an interesting research field in the scientific community.

As FW has a high moisture content and is readily biodegradable, it serves as a perfect substrate for anaerobic digestion (AD) (Kirchmayr et al., 2003; Zhang et al., 2007). The AD process is characterized by a series of biochemical transformations brought about by microbial consortia, which convert complex macromolecules into low molecular weight compounds such as biomethane, carbon dioxide, water and ammonia (Mudhoo and Kumar, 2013). Treating FW with AD produces renewable energy and yields a reduction of the amount of waste and greenhouse gas (GHG) emissions. Curry and Pillay (2012) estimated the potential energy recovery from FW based on the FAO studies, and suggested that 1.3 billion ton of waste can produce 894 TWh/year, which is approximately 5% of the total global electrical energy utilization. Nevertheless, the long retention time of the AD process is a major concern. Therefore, to accelerate the process and to enhance the biomethane production, methods for pretreating FW prior to the

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AD process have been developed (Carlsson et al., 2012; Esposito et al., 2011a, 2011b; Mata-Alvarez et al., 2000; Carrere et al., 2010).

Various mechanical, biological, chemical, thermal pretreatment methods or a combination of them can be applied for FW. The effects of various pretreatment methods are highly different depending on the characteristics of the substrates and the pretreatment type (Ariunbaatar et al., 2014). Although according to EU regulation EC1774/2002, FW is categorized as a catering waste, and it should be pasteurized or sterilized prior to or after AD (Kirchmayr et al., 2003). Taking this regulation into account, a thermal or a chemical pretreatment of FW could be more effective. These pretreatments could cause the degradation of complex molecules as well as the solubilization of recalcitrant particles, making the substrate more available for the anaerobes.

Thermal pretreatment is one of the easiest and most studied pretreatment methods and has already been applied at a full-scale (Carlsson et al., 2012; Carrere et al., 2010). Among various chemical methods, ozonation is an attractive method, as it does not increase the salt concentration in the reactor and does not have oxidant residues in the organic waste (Carrere et al., 2010). However, previous research on thermal and ozonation pretreatment methods have been conducted mostly on wastewater sludge, and only a few studies were conducted on the organic fraction of municipal solid waste (OFMSW) such as FW. Ma et al. (2011) obtained a 24% increase of biomethane production from FW with a thermal pretreatment at 120 °C, whereas Liu et al. (2012) obtained a 7.9% decrease of the biomethane production from FW with thermal pretreatment at 170 °C. Cesaro and Belgiorno (2013) obtained a negligible increase with ozonation pretreatment of source-separated OFMSW (SS-OFMSW).

To the best of our knowledge, no study has been conducted on the comparison of thermal and ozonation pretreatment to enhance the AD of FW. Therefore, this research aims at investigating the effects of thermal and ozonation pretreatments. A series of batch biomethane potential (BMP) tests were conducted to investigate the effect of temperature and treatment time of thermal and ozonation pretreatments. Moreover, the net energy production from applying these pretreatment methods, which could be used for a generation of electricity and heat, was estimated.

2. Materials and methods

2.1. Substrate and inoculum

MSW is the most complex solid waste stream, as opposed to more homogenous waste streams resulting from industrial or agricultural activities (Sim and Wu, 2010). The generation rate and composition of FW depends on many factors such as the region, season, culture, economic income and demographics. To reduce experimental bias due to the different compositions of collected FW, the substrate used for this research was synthetically generated based on an average compositional analysis of FW in some European countries, including UK, Finland, Portugal and Italy (Table 1) (MTT Agrifood Research Finland, 2010).

Table 1 shows the fractions of synthetic FW used in this experiment as well as the results from the study on mixed FW composition in selected European countries (MTT Agrifood Research Finland, 2010). In order to make the substrate preparation simpler, an assumption was made to eliminate the mixed meals, drinks and snacks fraction. The calculation was made assuming that the miscellaneous fraction of FW (25.8%) contains the same 58.4% fruits/vegetables, 3.6% pasta/rice, 4.7% bread/bakery, 6.1% meat/fish, 1.4% dairy products ratio, thus resulting in the additional distribution of the miscellaneous fraction over these known fractions. Based on the final concentration of the FW composition shown in Table 1, different types of uncooked food were mixed and blended in order to obtain a homogenized synthetic FW that represents the typical FW of the above-mentioned EU countries.

Table 1
Composition of synthetic FW used for the experiment.

% Wet weight fraction	Average from literature review (%)[a]	Distribution of miscellaneous fraction over the known[a] fraction (%)	Final concentration applied in the BMP test (%)
Fruits and vegetables	58.4	20.2	78.6–79.0
Pasta/rice/flour/cereals	3.6	1.3	4.9–5.0
Bread and bakery	4.7	1.7	6.4–6.0
Meat and fish	6.1	2.1	8.2–8.0
Dairy products	1.4	0.5	1.9–2.0
Miscellaneous	25.8	–	0
Total	100	25.8	100

[a] MTT Agrifood Research Finland (2010).

2.2. Pretreatment of FW

EU Regulation EC1774/2002 dictates that catering waste should be pasteurized at >70 °C for at least an hour, or at >133 °C for 20–30 min. With respect to this regulation, pretreatment at 70–140 °C for an hour and at 140–150 °C for 30 min was conducted to investigate their potential to enhance the AD of FW. Moreover, a set of experiments was subsequently conducted if a longer pretreatment time could result in a further enhancement of the biomethane production. Pretreatment times of 1.5, 4 and 8 h were investigated at the selected temperature.

A simple oven (WTC Binder) was used for the thermal pretreatment. The FW was directly put in a 1 L glass bottle GL 45 (Schott Duran), and then placed inside the oven. After the pretreatment, the bottle was cooled until room temperature and it was directly used for the BMP tests.

There are no regulations for ozonation pretreatment of FW prior to AD. An UV generator (model-Fischer) was used for the ozonation pretreatment. It produces 0.6 mmol O_3 with a flow rate of 35 L/hour using ambient air. The FW was placed in a vessel with inlet and outlet tubes. The ozone was introduced from the bottom for 10–60 min, and forced to flow out from the top, which generated 0.168–1.008 gO_3. Four concentrations (0.034 gO_3/gTS, 0.068 gO_3/gTS, 0.101 gO_3/gTS, 0.202 gO_3/gTS) of ozone doses were applied at room temperature prior to the BMP test. To reduce the potential ozone inhibition that can have an immediate killing effect on anaerobic microbes, the vessel was flushed with nitrogen gas after ozonation.

2.3. Biomethane potential test

As there is no standard protocol for BMP tests (Raposo et al., 2011; Esposito et al., 2012a), the most common reported method was applied (Raposo et al., 2011; Esposito et al., 2012a, 2012b, 2012c; Browne and Murphy, 2013). BMP tests were conducted in a 1 L glass bottle at mesophilic (32–34 °C) conditions. All the bottles were in duplicates and were placed on a magnetic stirrer (model-VELP) to provide continuous mixing. The substrate to inoculum (S/I) ratio was 0.5 gVS/gVS. The inoculum used for the BMP tests was from a full-scale AD plant located in Capaccio-Salerno (Italy). The plant treats the buffalo dung together with the milk whey and sewage sludge generated from the mozzarella producing industry. The expected microbial consortia responsible for the AD process would be the typical methanogens most commonly found in rumen, i.e. *Methanobrevibacter*,