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Assessing the variability in biomethane production from the organic fraction of municipal solid waste in batch and continuous operation

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HIGHLIGHTS

- Eight organic waste streams were examined for biochemical methane potential (BMP).
- Commercial food waste produced 560 mL CH_4 g VS^{-1} in continuous trials.
- Raising the loading rate to 4 kg VS m^{-3} day^{-1} led to a reduction in methane yield.
- The low C:N ratio led to levels of 7000 mg N L^{-1} at high loading rates.
- Free ammonia levels of 1000 mg N L^{-1} were encountered at a pH of 8.

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ABSTRACT

This paper examines the variability in biomethane potential from the organic fraction of municipal solid waste depending on source of origin. Eight organic waste streams were examined for biochemical methane potential (BMP). Specific methane yields of between 274 and 368 mL CH_4 g VS^{-1} for household waste and 491–535 mL CH_4 g VS^{-1} for commercial waste were achieved. Inclusion of garden waste reduced methane yields. A continuous trial on commercial food waste produced an average of 560 ± 29 mL CH_4 g VS^{-1} at a moderate organic loading rate (OLR) of 2 kg VS m^{-3} day^{-1} with a hydraulic retention time (HRT) of 30 days. Raising the OLR to 4 kg VS m^{-3} day^{-1} led to a reduction in specific methane yield. The low carbon to nitrogen (C:N) ratio of commercial food waste (14.4) led to process instability due to total ammonia nitrogen levels in excess of 7000 mg L^{-1} towards the end of the trial.

1. Introduction

Many municipal organic waste streams are dominated by food waste, particularly catering premises such as restaurants, hotels and office canteens. In the Republic of Ireland, food waste accounts for approximately 25% of domestic household and 40% of commercial waste [1]. The organic fraction of municipal solid waste (OFMSW) is a term often used in Ireland and the UK to describe food and garden waste in household and commercial waste streams. In many EU countries OFMSW is simply referred to as biowaste. National and European legislation places restrictions on the amount of OFMSW which may be sent to landfill [2] while the current EU Waste Framework Directive [3] seeks to encourage waste separation at source and biological treatment of OFMSW. Anaerobic digestion (AD) is a mature biotechnology which can maximise the value of organic waste. The methane component of biogas, produced from the anaerobic process, is a valuable renewable gaseous fuel. The digestate from the biogas process may be used as a mineral rich fertilizer and reduce synthetic fertilizer consumption [4].

One of the objectives of this paper is to outline the variability in methane yields from OFMSW depending on the waste source and type of collection. A selection of organic waste samples from domestic, commercial and food processing waste streams were investigated. The biochemical methane potential (BMP) test was used to assess the methane yield for each substrate. In addition to the BMP tests, a continuous AD trial was carried out for 25 weeks using commercial canteen food waste as substrate to examine the effects of organic loading rate and hydraulic retention time on the specific methane yield.

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2. Materials and methods

2.1. Collection, preparation and characterisation of waste samples

Samples were collected in a large centralised facility (Acorn Recycling Ltd.) licensed to treat 45,000 tonnes per annum of OFMSW (referred to as brown bin waste in Ireland). This facility treats a wide range of municipal organic waste streams from across the province of Munster in Ireland (population circa 1.25 million people). As shown in Fig. 1, a total of 8 different waste streams were sampled; 4 household, 2 commercial and 2 food processing streams. All waste streams identified were sampled frequently (samples taken from each incoming waste collection truck) over a 6 week period in autumn/winter to build up a representative sample of each waste stream. Previously only the commercial waste stream had been sampled in the summer time of the same year (2012) as the other waste streams were not available at that time. Samples of each waste stream were labelled and stored in a freezer at −20 °C until required. At the end of the sampling period, samples from each stream were defrosted at room temperature for 24 h and were then thoroughly mixed, screened for nonorganic material and macerated in a Buffalo food mincer to a particle size of less than 5 mm to form a large bulk sample for each waste stream. Approximately 10 kg of material was then sub-sampled from the bulk sample of each waste stream following the German VDI guidelines on sampling solid material [5]. All sub-samples were stored in a freezer at −20 °C until required as previously described by Browne et al. [6]. A proximate and elemental analysis was carried out in triplicate samples from each waste stream as shown in Table 1.

2.2. BMP tests

The apparatus used to conduct the BMP tests was the Automatic Methane Potential Test System II (Bioprocess Control Sweden AB). This laboratory instrument is specially designed for determination of the BMP of a substrate. The AMPTS II system consists of three major parts as follows:

1. A temperature controlled water bath with 15 bottle reactors of 500 mL volume, each equipped with a mixer that can be run in either continuous or intermittent mode.
2. A carbon dioxide fixing unit with an alkaline solution (3 N sodium hydroxide) that absorbs the carbon dioxide and hydrogen sulphide produced during the anaerobic digestion process.
3. A gas measuring unit consisting of 15 parallel operating cells, where the gas is measured through water displacement. When approximately 10 mL of gas has been accumulated each cell opens and releases the gas. For each opening, the time, temperature and pressure are registered and stored locally in an embedded Central Processing Unit (CPU). Based on these measurements, normalised (0 °C, 1 atm and dry gas) accumulated gas production and gas flow rate are calculated.

The BMP tests were performed with a working volume of 400 mL. The ratio of inoculum to substrate was chosen to be 2:1 on a volatile solids (VS) basis. The inoculum to substrate ratio is a critical parameter in conducting a BMP test according to the Anaerobic Digestion Specialist Group of the International Water Association [7]. A ratio of 2:1 or greater of inoculum to substrate on a VS basis is recommended for BMP trials by Raposo et al. [8] to limit any inhibitory effects due to the chemical composition of the substrate such as inhibition associated with accumulation of ammonia and volatile fatty acids (VFA) [8]. All samples were tested for BMP in triplicate. A BMP test of the inoculum alone (referred to as a blank) was conducted in triplicate. The average methane yield from the blanks was subtracted from the samples of OFMSW with inoculum to accurately assess the BMP yields from the samples only. A triplicate BMP test was also carried out on cellulose for quality control as the maximum BMP from cellulose is known and can be compared with the BMP yield. The percentage volatile solids destroyed during the batch process was calculated as follows:

$$\%\text{VS destruction} = 100 \cdot (1 - (\text{VS}_f - \text{VS}_{fb})/(\text{VS}_i - \text{VS}_{ib}) \quad (1)$$

where VS_i is the amount of total input VS (g), VS_f is the amount of total VS at the end of the BMP test (g), VS_{ib} is the amount of VS (g) in the inoculum (blank) at the beginning of the BMP test and VS_{fb} is the amount of VS (g) in the inoculum (blank) at the end of the test.

The Buswell equation was used to calculate the theoretical maximum methane potential [9].

$$\text{BMP}_{Th} = \frac{\left[\left(\frac{n}{2}\right) + \left(\frac{a}{8}\right) - \left(\frac{b}{4}\right)\right] \cdot 22400}{(12n + a + 16b)} \quad (2)$$

where n is the number of atoms of carbon; a is the number of atoms of hydrogen; b is the number of atoms of oxygen.

The biodegradability index is the ratio of the measured BMP divided by the theoretical methane yield according to the Buswell equation and is used to assess the level of biodegradability of a substrate.

2.3. Source and characteristics of inoculum for BMP tests

The inoculum for the BMP tests was obtained from a lab scale 300 L digester treating mostly cattle slurry and a small portion of

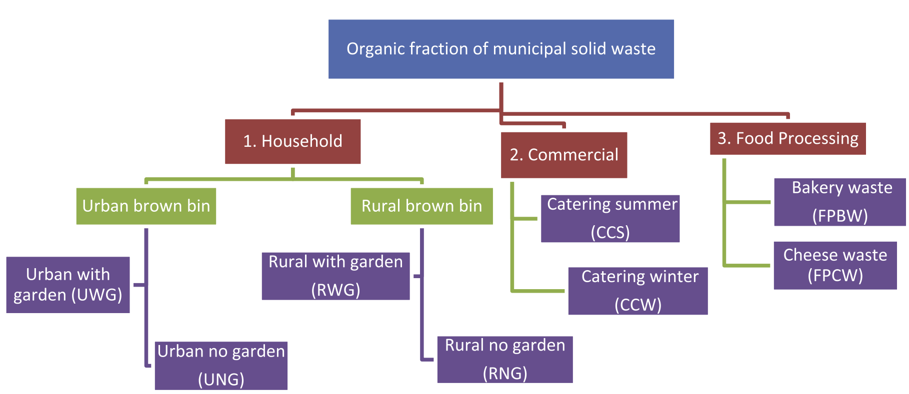

Fig. 1. Illustration of samples taken from the organic fraction of municipal solid waste (with and without garden waste).