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Anaerobic digestion of two biodegradable municipal waste streams

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ABSTRACT

Landfill avoidance for organic wastes is now a high priority worldwide. Two fractions of the municipal waste stream were considered with respect to their potential for diversion through controlled anaerobic digestion. The physical and chemical properties of source segregated domestic food waste (ss-FW) and of the mechanically-recovered organic fraction of municipal solid waste (mr-OFMSW) were analysed, and their methane yields determined in both batch and semi-continuous digestion. Methane potentials were compared with predicted values based on biochemical composition, elemental analysis and carbon mass balance, and the differences explained by compositional analysis of feedstocks and digestates. The ss-FW had a higher percentage biodegradability and higher energy potential on a dry weight basis due to the high proportion of proteins and fats in this waste, although the energy potential of the mr-OFMSW was slightly higher on a wet weight (WW) basis. The mr-OFMSW showed very stable digestion characteristics, whereas the ss-FW had a high digestate ammoniacal-N concentration and volatile fatty acid accumulation leading to some process instability. Digestates from semi-continuous trials with mr-OFMSW had high concentrations of potentially toxic elements (PTE) and a lower nutrient content than ss-FW digestate, making the former unsuitable for application to land used in food production.

1. Introduction

It is now widely accepted that anaerobic digestion can offer a sustainable means of processing the organic fraction of municipal solid waste (OFMSW), and provides a route by which some of the energy inherent in this material can be recovered (Mata-Alvarez, 2003). There is also the added potential of using digestate from the process as a fertiliser and soil-conditioning material which, if it is of suitable quality, can be applied to agricultural land for food production (Lukehurst et al., 2010). There are several reasons why European countries are rapidly expanding the application of this technology in municipal waste management. These include: the requirements of the EU Landfill directive (99/31/EC) (EC, 1999); challenging policies on municipal waste in the EU Waste Framework directive (2008/98/EC) (EC, 2008); the potential to provide a means of satisfying the Animal By-Products Regulations (EC 1069/2009) (EC, 2009a); and the need for alternative and energetically more efficient routes than composting or incineration for the recovery of value from wet materials such as food waste, driven in part by European targets for renewable energy production (2003/30/EC and 2009/28/EC) (EC, 2003, 2009b).

The current research examined the energy yield and digestate characteristics of two fractions of municipal waste that can be separated and targeted for resource recovery through the digestion process. The first was the organic fraction recovered from mixed residual waste by post-collection mechanical sorting. The second was source segregated food waste collected separately from households in biodegradable cornstarch bags. The physico-chemical characteristics of the wastes were determined and digestion trials were carried out in both batch and semi-continuous anaerobic digesters. Digestion performance was quantified by methane production and solids destruction, process stability assessed by analysing digester chemical parameters, and digestate quality referenced by the concentration of potentially toxic elements (PTE) and its nutrient properties. In addition, elemental composition and calorific values of the wastes were determined to allow comparison of experimental results with theoretical predictions of biogas yield.

2. Materials and methods

2.1. Feedstocks

2.1.1. Food waste

The source-segregated domestic food waste (ss-FW) originated from a collection scheme at Newtown, Powys, UK which yields about 750 tonnes year^{-1} of this material. A 210 kg sample was collected at the Biocycle anaerobic digestion plant in Ludlow, Shropshire, UK. The sample was removed from biodegradable starch-based bags and processed in a commercial shear shredder (RS404S, Untha Ltd,

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Germany) with 4 counter-rotating shaft-mounted cutters, a 20 mm jaw spacing and an 80 mm rejection screen. Rejected material was subsequently recycled through the shredder until all material had passed the screen. The sample was then further processed by passing through a macerating grinder (S52/010 Waste Disposer, IMC Ltd, UK), and mechanically mixed in a single container until homogeneous.

2.1.2. Residual waste

Mechanically-recovered OFMSW (mr-OFMSW) was obtained from the Bursom Recycling Centre, Leicester (Biffa Plc, UK). The residual mixed waste entering this plant is first ball milled and then separated into two size fractions of 0–40 mm and 40–80 mm by a drum screen. The 0–40 mm fraction (mainly putrescibles) goes through a flip-flop slotted screen to remove excess water and then through a 5 mm grid. The material is then transferred to closed containers for transport to the Wanlip anaerobic digestion plant (Biffa Plc, UK). 100 kg of this material was taken as a sample and further hand-sorted to remove large non-organic contaminants.

Both of the wastes were stored in sealed containers at approximately −20 °C, and thawed for 24 hours at room temperature before use. Once defrosted the waste was maintained at 4 °C and used within 5 days.

2.2. Feedstock particle size analysis

The particle size distribution (PSD) of a 30 kg sample of the mr-OFMSW was analysed using a British Standard test sieve shaker (Endecotts Ltd, UK) with mesh sizes of 37.5, 20.0, 13.2, 6.7, 5.0 mm, for a 20-minute period. The PSD was expressed as a percentage of the weight of fresh matter present in each size class. To determine the particle size of the ss-FW it was diluted to give a slurry with a solids content of approximately 5% (w/v), and then analysed using a manual wet sieving technique (Mahmoud et al., 2006) with standard test sieves (Endecotts Ltd, UK) of mesh sizes of 4.75, 2.80, 1.40, and 0.60 mm. The screened undersize material (<0.60 mm) was collected in two 25-litre containers and centrifuged to concentrate the finest particles prior to weight determination. The waste retained on each sieve was rinsed off with tap water and dried at 105 °C to constant weight, and the result expressed as a percentage of the total solids weight fraction for each mesh size.

2.3. Testing for biochemical methane potential (BMP)

BMP tests were performed according to the recommendations of Angelidaki et al. (2009) using batch digesters with a working volume of 1.4 l, which were mechanically stirred at 40 rpm and maintained at 36 ± 1 °C in a thermostatic water bath (see Fig. S1 and S2 in the supplemental materials for the photo and schematic diagram of the BMP apparatus.). Biogas was collected by displacement of a 75% saturated sodium chloride solution acidified to pH 2 in calibrated glass cylinders (Walker et al., 2009). The height of the solution in the collection cylinder was recorded at 5-minute intervals by a headspace pressure sensor, as a back-up to manual readings. Vapour pressure and salt solution density were taken into

Table 1
Characteristics of the waste streams.

	ss-FW	mr-OFMSW
General		
pH (1:5)	4.71 ± 0.01	6.39 ± 0.01
TS (% wet weight (WW))	23.74 ± 0.08	52.83 ± 0.63
VS (% WW)	21.71 ± 0.09	33.55 ± 0.63
VS (% of TS)	91.44 ± 0.39	63.52 ± 1.89
Total Organic Carbon (TOC) (% of TS)	47.6 ± 0.5	34.8 ± 1.1
TOC/TKN	13.9 ± 0.2	25.0 ± 1.6
Biodegradable C[a]/TKN	13.6 ± 0.2	19.2 ± 1.6
Calorific value (CV) (kJ g^{-1} TS)	20.7 ± 0.2	13.9 ± 0.2
Biochemical composition (VS basis)		
Carbohydrates[b] (g kg^{-1})	453 ± 17	340 ± 7
Lipids[c] (g kg^{-1})	151 ± 1	68.6 ± 5.4
Crude proteins (g kg^{-1})	235 ± 3	130 ± 7
Hemi-cellulose (g kg^{-1})	38.1 ± 3.7	52.2 ± 12.4
Cellulose (g kg^{-1})	50.4 ± 1.6	252 ± 36
Lignin (g kg^{-1})	16.5 ± 0.2	184 ± 26
Nutrients and PTE (TS basis)		
TKN (g kg^{-1})	34.2 ± 0.4	13.9 ± 0.8
Total Phosphorus (TP) (g kg^{-1})	5.41 ± 0.32	2.17 ± 0.25
Total Potassium (TK) (g kg^{-1})	14.3 ± 0.8	4.26 ± 0.37
Cd (mg kg^{-1})	<1.0	1.50 ± 0.37
Cr (mg kg^{-1})	29.0 ± 1.2	263 ± 11
Cu (mg kg^{-1})	7.20 ± 0.81	107 ± 10
Hg (mg kg^{-1})	<0.010	0.179 ± 0.018
Ni (mg kg^{-1})	7.0 ± 2.9	97.0 ± 2.9
Pb (mg kg^{-1})	<10	162 ± 10
Zn (mg kg^{-1})	33 ± 11	259 ± 4
Elemental composition (TS basis)		
N (%)	3.44 ± 0.04	1.32 ± 0.08
C (%)	47.6 ± 0.5	33.0 ± 1.0
H (%)	7.04 ± 0.63	4.80 ± 0.30
S (%)	0.15 ± 0.01	0.25 ± 0.04
O (%)	33.3 ± 2.6	22.2 ± 1.2

[a] Biodegradable carbon was calculated by deducting lignin carbon from TOC. The formula of lignin was chosen as $C_9H_{7.95}O_{2.41}(OMe)_{0.93}$ (Sakakibara, 1980).
[b] In equivalent glucose.
[c] *n*-Hexane extractable material (HEM).

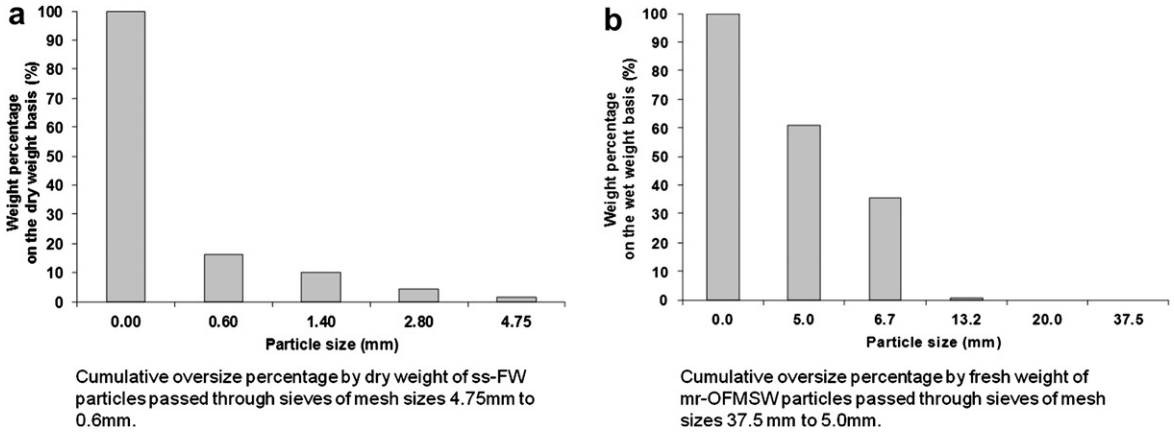

Fig. 1. Particle size distribution of ss-FW and mr-OFMSW.