Waste Management 36 (2015) 147–155

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials

Luca Alibardi [a,*], Raffaello Cossu [b]

[a] Department of Civil, Environmental and Architectural Engineering, University of Padova, Via Marzolo 9, 35131 Padova, Italy
[b] Department of Industrial Engineering, University of Padova, Via Marzolo 9, 35131 Padova, Italy

ARTICLE INFO

Article history:
Received 11 August 2014
Accepted 14 November 2014
Available online 16 December 2014

Keywords:
Anaerobic digestion
Biological hydrogen production
Dark fermentation
Organic fraction municipal solid waste
Waste composition

ABSTRACT

The composition of the Organic Fraction of Municipal Solid Waste (OFMSW) strongly depends on the place and time of collection for a specific municipality or area. Moreover synthetic food waste or organic waste from cafeterias and restaurants may not be representative of the overall OFMSW received at treatment facilities for source-separated waste. This work is aimed at evaluating the composition variability of OFMSW, the potential productions of hydrogen and methane from specific organic waste fractions typically present in MSW and the effects of waste composition on overall hydrogen and methane yields. The organic waste fractions considered in the study were: bread–pasta, vegetables, fruits, meat–fish–cheese and undersieve 20 mm. Composition analyses were conducted on samples of OFMSW that were source segregated at household level. Batch tests for hydrogen and methane productions were carried out under mesophilic conditions on selected fractions and OFMSW samples. Results indicated that the highest production of hydrogen was achieved by the bread–pasta fraction while the lowest productions were measured for the meat–fish–cheese fraction. The results indicated that the content of these two fractions in organic waste had a direct influence on the hydrogen production potentials of OFMSW. The higher the content of bread–pasta fraction, the higher the hydrogen yields were while the contrary was observed for the meat–fish–cheese fraction. The definition of waste composition therefore represents fundamental information to be reported in scientific literature to allow data comparison. The variability of OFMSW and its effects on hydrogen potentials might also represents a problematic issue in the management of pilot or full-scale plants for the production of hydrogen by dark fermentation.

1. Introduction

The Organic Fraction of Municipal Solid Waste (OFMSW) is characterised by high moisture and high biodegradability due to a large content of food waste, kitchen waste and leftovers from residences, restaurants, cafeterias, factory lunch-rooms and markets (Zhang et al., 2007; Lebersorger and Schneider, 2011). In view of these characteristics, OFMSW represents the main source of adverse environmental impacts and risks in traditional landfilling (odours, fires, VOC's, groundwater contamination by leachate, global climate changes, etc.) (i.a. Manfredi et al., 2010; Thomsen et al., 2012; Beylot et al., 2013). Consequently European and national legislation has focused on diverting OFMSW from landfilling (Cossu, 2009). Management options are therefore aimed at stabilising OFMSW by means of different technologies, based either on thermal (e.g. incineration) or, more frequently, on biological processes (composting, anaerobic digestion). Thermal treatment is limited by the low heating values of OFMSW (Nelles et al., 2010) while composting, although a well-established process, features several disadvantages in term of energy consumption and problems in compost market (Meyer-Kohlstock et al., 2013; Morris et al., 2013).

In this framework, interest for anaerobic digestion (AD) has been growing steadily over recent decades, being promoted more and more frequently by national programmes for the production of energy from renewable resources. AD processes also have the potentials to evolve towards technologies generating valuable industrial precursors for fuels and plastic productions; moreover AD processes are viewed as the best option for use in the biological production of methane and hydrogen, the latter being recognized as one of the most interesting and promising forms of biofuel (Clarke and Alibardi, 2010; Guo et al., 2010; Ozkan et al., 2010; De Gioannis et al., 2013).

* Corresponding author at: Department of Civil, Environmental and Architectural Engineering, University of Padova, Via Marzolo 9, 35131 Padova, Italy.
E-mail address: luca.alibardi@unipd.it (L. Alibardi).

http://dx.doi.org/10.1016/j.wasman.2014.11.019
0956-053X/

Biological hydrogen production from OFMSW by dark fermentation fits perfectly with the concepts for modern sustainable waste management, allowing the stabilisation of waste and production of renewable energy (Kapdan and Kargi, 2006; Hallenbeck, 2009). For a full-scale application of the dark fermentation process to OFMSW, in-depth knowledge of the effects of operating conditions on the hydrogen conversion efficiency is required. The hydrogen production potential via dark fermentation depends on several aspects related to the type and treatment of inoculum, type of reactor, organic loading rate and hydraulic retention time, process temperature and pH conditions (Wang and Wan, 2009; Guo et al., 2010; Nanqi et al., 2011). Different process conditions and specific aspects of the dark fermentation process have been analysed, although the results remain controversial, at times lacking direct comparability and at time being divergent or even antithetic (De Gioannis et al., 2013).

To the best of the Authors' knowledge, an aspect that has not yet been addressed is the influence of the OFMSW composition variability on the process efficiency. From the point of view of chemical composition, OFMSW contains various substances belonging to the three main groups of biodegradable organics: carbohydrates, proteins and lipids. Presence of the different substances is influenced by numerous social and economical aspects, largely related to food availability, seasonal variation and consumption patterns, with the composition of OFMSW consequently being heavily dependent on the generating source and the collection time in a specific municipality or area (Kobayashi et al., 2012). Moreover, the substrates used in research experiments on OFMSW may comprise fresh food (raw or cooked/boiled) used to simulate real waste, food waste taken from restaurants or university cafeterias or, in a few cases, organic waste from household waste collection. Waste from cafeterias and restaurants, however, may not be representative of the overall OFMSW reaching treatment facilities for source-separated waste (Zhou et al., 2013). The different origins and compositions of the organic waste samples, coupled with different process conditions, might therefore affect the high variability of hydrogen production yields reported in literature. As reported in Table 1, the origins of organic waste used for research studies are often dining halls and cafeterias, data on waste composition may either be unreported or reported in an unrepeatable form (wet weight) with hydrogen production potentials resulting in a variability of orders of magnitude in spite of the use of apparently similar substrates. The failure to always specify the composition of organic waste may complicate the drawing of conclusions as to whether a type of organic or food waste used in an experimental study has a higher or lower hydrogen yields than another, due to the presence of better operating conditions or simply because the organics in that particular waste have higher hydrogen production yields. Waste composition and its variability may consequently influence hydrogen production potentials of OFMSW.

Laboratory scale batch tests known as Biochemical Methane Potential (BMP) are frequently used in anaerobic digestion to evaluate the potential production of methane and biogas from wastewater, sludge, organic waste and agricultural biomass. BMP tests are also used to evaluate and compare particular digestion conditions (e.g. co-digestion) or effects of substrate pre-treatment. Scientific literature reports the basic requirements to carry out BMP tests at optimal conditions (Hansen et al., 2004; Angelidaki et al., 2009) and inter-laboratory tests are carried out to validate results from different BMP test procedures (Raposo et al., 2011; Porqueddo et al., 2013). The methane potential productions of waste materials with similar composition or origin are presumed to yield results within narrow ranges of variability.

In this framework, the study aims to evaluate the effects of the composition variability of OFMSW on hydrogen and methane production potentials in order to assess the importance of waste composition on final results and for the purpose of data comparison.

2. Materials and methods

2.1. OFMSW samples

Five samples of OFMSW were collected from the waste receiving area of an anaerobic digestion plant treating organic waste located in Padova, Italy. The samples were collected in five different months: February, May, July, October and November 2012. The OFMSW delivered at the plant is source segregated at household level and the collection area involves a population of about 130,000 inhabitants.

For all samples, approximately 200 kg of organic waste was manually sieved, sorted and divided into the following fractions: fruits (F), vegetables (V), meat–fish–cheese (MFC), bread–pasta (BP), undersieve 20 mm (U) and rejected materials. Undersieve 20 mm was composed of materials smaller than 20 mm. The rejected materials were shoppers, plastics, paper and cardboard, metals, glass, bones, shells and fruit kernels.

Samples of the sorted fractions were transported to the laboratory after each sorting campaign and immediately stored in fridge at +4 °C. Due to the heterogeneity of the OFMSW, a collection of small samples for testing was not representative of actual waste composition. Therefore, in this study, particular emphasis was placed on the preparation of representative samples of sampled OFMSW; samples of single fractions (more homogeneous) were used to prepare the OFMSW mixture detected during the sorting campaigns by maintaining the same proportions, after excluding the rejected materials. Subsequently, all samples (single fractions and OFMSW mixture) were shredded in a kitchen mill and stored in a freezer at −20 °C.

The samples of organic waste and sorted fractions were analysed for the following parameters: total solids (TS) and volatile solids (VS), total organic carbon (TOC), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonium (NH_4^+) and total phosphorus (P_{tot}) concentrations.

2.2. OFMSW samples with specific composition

To evaluate the effects of carbohydrate, protein and lipid-rich fractions on hydrogen and methane potential productions, three mixtures of OFMSW were prepared using single fractions obtained during the last sorting campaign dated November 2012. The three mixtures were named Mix A, Mix B and Mix C. The composition of the three mixtures is reported in Table 2. The three mixtures simulated three waste compositions with different contents of BP and MFC fractions in order to evaluate the effects of carbohydrate rich and protein–lipid rich fractions on hydrogen production potential of the entire OFMSW mixture. Sample Mix A was prepared using a high content of BP fraction (50%), while sample Mix B was prepared with 50% MFC fraction. The third sample, Mix C was composed of an intermediate content of these two fractions, 36% BP and 19% MFC. In the three samples, the fractions F, V and U were 10%, 20% and 15% respectively. All percentages are expressed on VS basis. Following preparation the three mixtures were analysed for the following parameters: volatile solids (VS), total organic carbon (TOC), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonium (NH_4^+) and total phosphorus (P_{tot}) concentrations. To provide for a detailed assessment of the type of organics present in each mixture, the following groups of organics were analysed: proteins, lipids, carbohydrates, hemicellulose, cellulose, lignin, starch, glucose, fructose, sucrose and pectins.