

Biogas yield from Sicilian kitchen waste and cheese whey

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Abstract

The aim of this study is to determine the chemical composition of kitchen waste and cheese whey, as well as the biogas yield obtained from the Anaerobic Digestion (AD) tests of these two raw materials.

Since the separated waste collection is performed in the town of Marineo (Palermo), a sample of kitchen waste, different from food industry one and included in the Organic Fraction of Municipal Solid Waste (OFMSW), was collected from the mass stored at the households of this town. Moreover, a sample of cheese whey was collected in a Sicilian mini dairy plant, where sheep milk is processed. This investigation was carried out inside laboratory digesters of Aleksandras Stulginskis University (Lithuania). Total Solids (TS) resulted 15.6% in kitchen waste and 6% in cheese whey, while both the raw materials showed a high content of organic matter, 91.1% and 79.1%, respectively. The biogas yield resulted 104.6 l kg⁻¹ from kitchen waste and 30.6 l kg⁻¹ from cheese whey. The biogas yield from TS resulted 672.6 l kg⁻¹ using kitchen waste and 384.7 l kg⁻¹ using cheese whey. The biogas yield from Volatile Solids (VS) resulted 738.9 l kg⁻¹ using kitchen waste and 410.3 l kg⁻¹ using cheese whey.

Introduction

The Organic Fraction of Municipal Solid Waste (OFMSW) and/or food industry by-products (e.g. cheese whey) and/or animal manure

can be processed through Anaerobic Digestion (AD), in order to produce biogas and “digestate”. The biogas, mostly containing methane, can be transferred to the natural gas distribution pipeline or Combined Heat and Power (CHP) plants or used as vehicle fuel, while the digestate can be used as bio-fertiliser.

The chemical composition of OFMSW and, therefore, the yield of AD process, is influenced by several factors, including climate, collection frequency and method, season, cultural practices, as well as changes in its solid components (Tchobanoglous *et al.*, 1997; Mace *et al.*, 2000; Pavan *et al.*, 2000; Saint-Joly *et al.*, 2000; Bolzonella *et al.*, 2003a, 2003b, 2005). Several papers focused on the AD of organic wastes according to their origin, e.g. OFMSW (Bolzonella *et al.*, 2005), household (Krzystek *et al.*, 2001) and kitchen waste (Rao and Singh, 2004). Many examples exist on the use of AD to treat the mechanically separated biodegradable fraction of municipal waste (Mata-Alvarez, 2003). There are also examples of the processing of mixed source segregated biodegradable wastes, e.g. kitchen and garden wastes (Archer *et al.*, 2005), but there are only a few reports on AD plants entirely processing household food waste separated at source (Banks *et al.*, 2011). The interest in this process is growing in Europe, due to the rising energy costs of wet waste processing, the requirement to meet the targets of the EU Landfill Directive (99/31/EC) (EU, 1999) and the need to comply with regulations for the disposal of animal by-products (EU, 2002). According to the regulations of many European countries, whether the waste is not separated at source but the organic fraction is recovered through a Mechanical-Biological Treatment (MBT) plant, the digestate produced is not allowed to be applied on land (Stretton-Maycock and Merrington, 2009). As a consequence, governments and industry are strongly interested in the AD methods of household food waste separated at source (Banks *et al.*, 2011).

Furthermore, kitchen waste was also surveyed as co-substrate for AD (Angelidaki and Ahring, 1997; Brinkman, 1999; Comparetti *et al.*, 2013). Anaerobic co-digestion of mixtures including food industry by-products and animal manure was previously investigated and, among these mixtures, particular interest was paid to the co-digestion of animal manure and cheese whey (Ghaly, 1996; Gelegenis *et al.*, 2007). Several authors focused on the AD of cheese whey for biogas production (Lo and Liao, 1986; Yan *et al.*, 1989; Ghaly and Pyke, 1991). Some studies showed that the co-digestion of cheese whey and other substrata (*i.e.* maize silage, beet pulp, carrot residues and glycerine fraction) can be advantageous inside lab-scale bio-reactors (Kacprzak *et al.*, 2010).

In this perspective the aim of this study is to determine the chemical composition of kitchen waste and cheese whey, as well as the biogas yield obtained from the AD tests of these two raw materials.

Materials and methods

Since the separated waste collection is performed in the town of

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Marineo (Palermo), a sample of kitchen waste, different from food industry one and included in the Organic Fraction of Municipal Solid Waste (OFMSW), was collected from the mass stored at the households of this town in a day of March 2012.

Moreover, a sample of cheese whey was collected in a Sicilian mini dairy plant, located in Ventimiglia di Sicilia (Palermo) and processing sheep milk, in the same day.

The two samples were transported to the Institute of Energy and Biotechnology Engineering of Aleksandras Stulginskis University (Lithuania).

In the laboratory of this institute, the Total Solids concentration (TS) was determined in each of the two samples, by drying it in an oven at 105 ± 2 °C temperature for 24 hours, as well as Volatile Solids concentration (VS), by burning it at 500 °C temperature. Total organic Carbon concentration (C_T) was determined in each sample, by using an analyser TOC II, as well as Total Nitrogen concentration (N_T), by using a Kjeldahl apparatus.

The AD tests were carried out in two laboratory scale anaerobic digesters under controlled temperature (38 ± 0.5 °C). The sample of kitchen waste (having a mass of 336 g) was added to a laboratory digester, consisting of stainless steel vessels (having a volume of 20 l) equipped with a substrate mixer (having a mixing intensity of 60 min⁻¹). Instead, the sample of cheese whey (having a mass of 26 g) was added to a digester having a volume of 0.5 l. The biogas produced was collected at the top of each digester and conveyed, through a drum type flow meter, to a gasholder (Tedlar® bag, having a volume of 25 l). Later the biogas collected was analysed by using a Schmock SSM 6000 biogas analyser.

The AD tests of kitchen waste were performed in three replications and those of cheese whey in nine replications.

The AD results of kitchen waste and cheese whey were evaluated by means of the following indicators: biogas production intensity *b*, biogas yield from biomass *B_M*, biogas yield from biomass Total Solids *B_{TS}*, biogas yield from biomass Volatile Solids *B_{VS}*, energy obtained from biomass *e_M*, from biomass Total Solids *e_{TS}* and from biomass Volatile Solids *e_{VS}*. Biogas production intensity *b* indicates the volume of biogas produced during the time of biomass biological degradation. Biogas yield from biomass *B_M*, from biomass Total Solids *B_{TS}* and from biomass Volatile Solids *B_{VS}* was calculated by means of the following equations (Navickas *et al.*, 2003) :

$$B_M = \frac{b_{dt}}{m}; \quad B_{TS} = \frac{b_{dt}}{m_{TS}}; \quad B_{VS} = \frac{b_{dt}}{m_{VS}} \quad (\text{Eq. 1, Eq. 2, Eq. 3})$$

where :

b_{dt} is the volume (l) of the biogas produced (in laboratory) during the time interval *dt* (duration of biomass biological degradation);
m is the mass (kg) of the biomass sample analysed;
m_{TS} is the mass (kg) of Total Solids in the biomass sample;
m_{VS} is the mass (kg) of Volatile Solids in the biomass sample.

The energy obtained during AD from biomass *e_M*, *e_{TS}*, *e_{VS}* was determined by means of the following equations :

$$e_M = B_M \cdot e_b; \quad e_{TS} = B_{TS} \cdot e_b; \quad e_{VS} = B_{VS} \cdot e_b \quad (\text{Eq. 4, Eq. 5, Eq. 6})$$

where :

e_b is the energetic value of biogas (MJ·m⁻³), depending on methane concentration in biogas (%).

The energetic value of biogas was determined by means of the following equation :

$$e_b = 0.0353 \cdot \frac{C_M}{100} \quad (\text{Eq. 7})$$

where :

C_M is the methane concentration in biogas (%).

Results and discussion

The chemical composition of kitchen waste and cheese whey samples are shown in Table 1. Total Solids (TS) resulted 15.6% in kitchen waste and 6% in cheese whey, while both the raw materials showed a high content of organic matter, 91.1% and 79.1%, respectively.

Optimum C/N ratios are generally in the 20-30 range in anaerobic digesters (Themelis and Verma, 2004; Ward *et al.*, 2008). The C/N ratio of kitchen waste resulted 17.4, while that of cheese whey resulted 23.1. Therefore, both values can be assumed to be optimal for AD process. However, Ward *et al.* (2008) reported in a review article that, after an acclimation period, anaerobic bacteria also accept lower C/N ratios (approximately 9).

The results of AD tests, whose duration was five days using kitchen waste and four days using cheese whey, are shown in Table 2.

The biogas yield resulted 104.6 l·kg⁻¹ from kitchen waste and 30.6 l·kg⁻¹ from cheese whey. The biogas yield from TS resulted 672.6 l·kg⁻¹ using kitchen waste (Figure 1) and 384.7 l·kg⁻¹ using cheese whey (Figure 2).

Table 1. Chemical composition of kitchen waste and cheese whey samples.

Parameter	Measurement unit	Kitchen waste	Cheese whey
Total Solids (TS)	%	15.6	6.0
Organic matter (in TS)	%	91.1	79.1
Organic Carbon	%	5.69	2.29
Total Nitrogen	%	0.328	0.099
C/N ratio	-	17.4	23.1

Table 2. Results of AD tests.

Indicator	Rate	Kitchen waste	Cheese whey
Biogas yield from biomass, <i>B_M</i>	l·kg ⁻¹	104.6	30.6
Biogas yield from Total Solids, <i>B_{TS}</i>	l·kg ⁻¹	672.6	384.7
Biogas yield from Volatile Solids, <i>B_{VS}</i>	l·kg ⁻¹	738.9	410.3

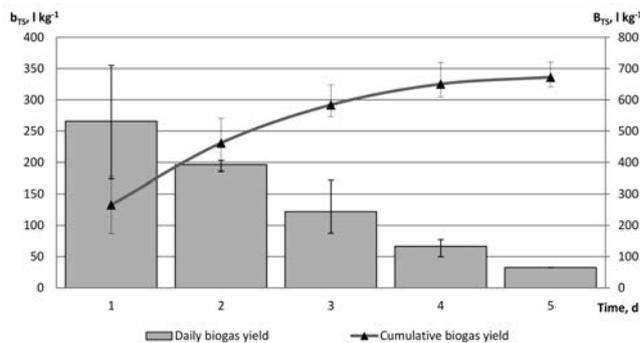


Figure 1. Biogas yield from Total Solids (TS) obtained using kitchen waste during AD tests: the histograms are the daily yield *b_{TS}*, while the curve is the total cumulative yield *B_{TS}*.

The biogas yield from Volatile Solids (VS) resulted 738.9 l kg^{-1} using kitchen waste (Figure 3) and 410.3 l kg^{-1} using cheese whey (Figure 4).

Furthermore, other indicators were determined for the kitchen waste sample: methane concentration in biogas of 61.9%, energy obtained from biomass (e_M) of 2.28 MJ kg^{-1} , energy obtained from dry matter (e_{TS}) of 14.67 MJ kg^{-1} and energy obtained from organic matter (e_{VS}) of 16.13 MJ kg^{-1} .

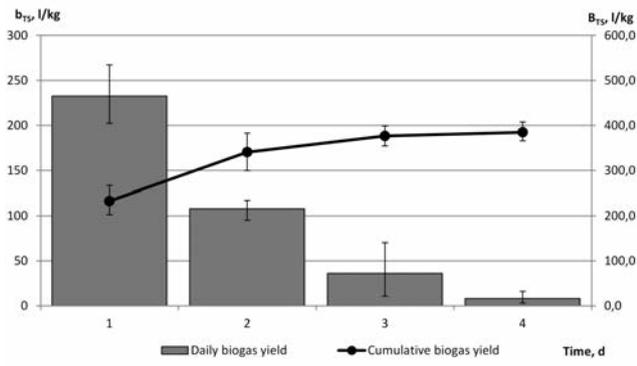


Figure 2. Biogas yield from Total Solids (TS) obtained using cheese whey during AD tests: the histograms are the daily yield b_{TS} , while the curve is the total cumulative yield B_{TS} .

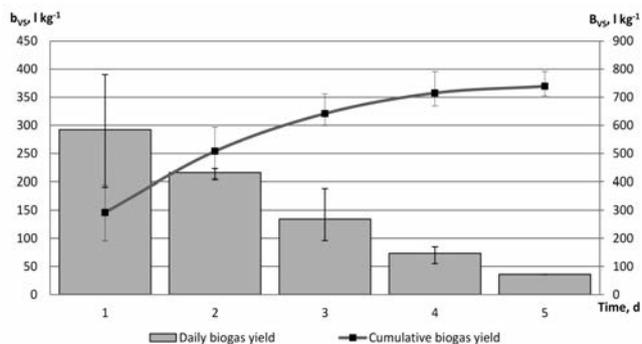


Figure 3. Biogas yield from Volatile Solids (VS) obtained using kitchen waste during AD tests: the histograms are the daily yield b_{VS} , while the curve is the total cumulative yield B_{VS} .

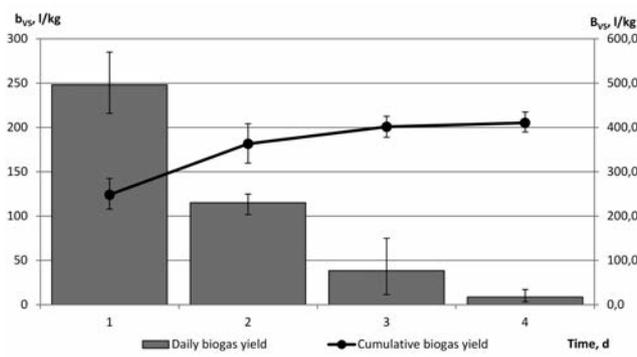


Figure 4. Biogas yield from Volatile Solids (VS) obtained using cheese whey during AD tests: the histograms are the daily yield b_{VS} , while the curve is the total cumulative yield B_{VS} .

Therefore, the biogas yield from VS using both the processed raw materials was comparable with the results of Banks *et al.* (2011) (642 l kg^{-1} with a methane concentration of 62%) and Bolzonella *et al.* (2006) (700 l kg^{-1} and 180 l kg^{-1} from sorted OFMSW with a methane concentration of 56%). However, the biogas yield from organic matter could be temporally variable, due to changing life style and consumed food composition.

Conclusions

Both kitchen waste and cheese whey are reasonable raw materials for biogas production, in terms of Total Solids (TS) and organic matter content, while the C/N ratio obtained (17-23) can be assumed to be optimal for AD process.

The time of biomass biological degradation was five days using kitchen waste and four days using cheese whey.

The biogas yield obtained using kitchen waste was 104.6 l kg^{-1} from biomass, 672.6 l kg^{-1} from TS and 738.9 l kg^{-1} from Volatile Solids (VS). The biogas yield obtained using cheese whey was 30.6 l kg^{-1} from biomass, 384.7 l kg^{-1} from TS and 410.3 l kg^{-1} from VS.

Waste management is a problem to be solved not only in Sicily but in the whole Italy, where the landfill sites have been or will be filled in with MSW very soon, as well as people don't accept the use of new sites in their municipal land. Moreover, the measures aimed at promoting segregated waste collection have been only scarcely implemented in Italy, where the environmentalist movements always fight against the building of incinerators, as well as the inefficient waste management has often caused public health problems in whole cities (*e.g.* Naples and Palermo).

In this perspective politicians should promote the valorisation of organic wastes (*e.g.* kitchen waste and cheese whey) through AD process. In fact, whether kitchen waste was anaerobically digested, it would highly reduce the OFMSW amount that is nowadays aerobically composted or, even worse, landfilled. Moreover, even if the biogas yield from cheese whey resulted about three times lower than that from kitchen waste, the AD of the liquid waste of dairies and mini dairy plants is an interesting option that would solve the problem of its disposal, better than others, *i.e.* purification, aerobic composting and feeding of pigs. These policy measures would contribute to reduce CO_2 emission and, therefore, global warming.

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