Short-time estimation of biogas and methane potentials from municipal solid wastes

(*Short title*: Short-time estimation of biogas produced from MSW)

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Abstract

BACKGROUND: Biogas (GB) and methane (BMP) potentials are important parameters to know the energy potential in the anaerobic digestion of municipal solid wastes (MSW) and to design full-scale facilities. However, no standard protocol is defined for this measure.

RESULTS: Several samples of mixed municipal solid waste (MSW) and the source-selected organic fraction of municipal solid waste (OFMSW) obtained at different stages of their mechanical-biological treatment were analyzed. GB and BMP values obtained at different times were correlated. Biogas potentials calculated at 3, 4, 5, 6, 7, 14, 21, 50 and 100 days correlated well for the OFMSW samples. In the case of the MSW samples, only GB values obtained at times of 14 or more days correlated well with the ultimate biogas production (considered at 100 days). The biogas potential analyzed at 21 days proposed in some standard methods accounted for the 77% of total biogas potential in the OFMSW samples and for the 71% in the MSW samples, respectively.

CONCLUSIONS: The results are useful for the correct design and operation of anaerobic digestion plants in terms of retention time estimation and to know the expected biogas and methane productions.

Keywords: Anaerobic digestion; Biogas; Waste treatment and waste minimization; Characterisation, Process optimisation, Residues.

INTRODUCTION

Generation of municipal solid wastes (MSW) is a worldwide problem for modern societies. As a consequence of the new regulations, the technologies based on biological treatments to reduce the biodegradable organic matter content of MSW have gained popularity. Among them, anaerobic digestion intended to obtain bioenergy in form of methane, composting or the combination of both in form of mechanical biological treatment plants (MBT) are the most advanced. Besides, since biogas and methane potentials can be considered reliable measures of solid waste biological stability, limits for the final disposal of treated organic wastes based on biogas production have been established or proposed in some European countries such as Germany,[1] Italy[2] and England and Wales[3].

Several studies related to the production of biogas and methane from different organic wastes have been published. In the field of MSW, the main objective of the published works is to determine the potential amount of biogas or methane that can be obtained from anaerobic digestion.[4] Source-separated collection systems for the organic fraction of MSW have been implemented in different European states. For this reason, the determination of the biogas and methane potentials of these wastes is of special interest. In other published studies, the main objective is to determine the optimal conditions of the biogas production tests.[5-7] Typically, the duration of these anaerobic tests is often long, which limits their application at industrial scale.

The objective of this research is to study in detail the biogas and methane productions of several samples of MSW from different origins and to obtain a general correlation between biogas and methane productions vs. time. This correlation can be useful for a rapid knowledge of MSW energy potential.

MATERIALS AND METHODS

Waste samples

Samples were obtained from different sources to include all the possible range of biogas and methane potentials. Table 1 shows the codification and treatment that correspond to each sample. Fresh (untreated) samples, such as the OFMSW and mixed MSW, were directly obtained from collection trucks. Three samples of each fraction were collected from six different municipalities near the city of Barcelona. Treated samples were obtained from a mechanical-biological waste treatment plant located in Barcelona (Spain) with a total capacity of 240,000 Mg per year.[8] Briefly, the plant operation is divided into three successive units: i) mechanical pretreatment, ii) anaerobic digestion (21 days) and iii) composting (2-4 weeks). The plant processes both the OFMSW and mixed MSW in two independent lines. Treated samples were obtained from different operations as coded in Table 1. Additionally, samples of baled landfilled municipal wastes (aged two years) were also analyzed (MSW-LF) to cover the presumably lowest value of biogas and methane potentials.

Analytical methods and biogas and methane production tests were carried out on a representative sample (approximately 40 kg). The sample was obtained by mixing four subsamples of about 10 kg each, taken from four different points of the bulk of material. Samples were immediately frozen and conserved at -20 ºC after collection. Before analysis, they were thawed at room temperature during 24 hours.

Biological methane production (BMP)

There is no a standardized method to determine the BMP and some methods have been proposed.[7,9] A modified method of the protocol described by the German Institute for Standardization reported in the Ordinance on the Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities[1] was used because of its simplicity and its wide use as official method in some European countries. This standard test provides the parameter GB_{21} for the biogas production (GB) expressed as liters of biogas measured under normal conditions produced per kg of initial sample dry matter (Nl kg^{-1} DM) during 21 days. In this study, biogas production was also monitored at different times and the test was finished when no biogas production was observed (100 days). The ratio inoculum:substrate used was 0.4:1 on dry matter basis and approximately 1:1 on Volatile Solids (VS) basis. No inhibition by the presence of VFA using this inoculum:substrate ratio was observed. This ratio was obtained after previous experiments for the optimization of the method with the wastes studied (data not shown). Inoculum was obtained from the full-scale anaerobic digester of the

MBT plant (7% of DM, 90% of VS on DM basis, pH=7.5). All the tests of biogas production were carried out in triplicate. The results are expressed as an average with standard deviation.

The biogas composition was analyzed by gas chromatography to obtain the biochemical methane production (BMP). The details of biogas analysis can be found elsewhere.[10]

Analytical Methods

Bulk density, water content, dry matter and volatile solids were determined according to the standard procedures.[11]

RESULTS AND DISCUSSION

Biogas and methane potential of different municipal solid waste samples

Table 2 shows the values obtained for biogas and biological methane potentials at 21 and 100 days. The dry matter and volatile matter content of the samples are also reported. GB_{100} for the OFMSW of fresh samples ranged between 270 and 575 Nl biogas kg^{-1} DM and BMP_{100} values ranged from 150 to 385 Nl CH_4 kg^{-1} DM. These values are similar to those previously reported by other authors for the total biogas and methane potentials.[4] GB_{100} and BMP_{100} values obtained for MSW were lower than those of the OFMSW due to the lower volatile and biodegradable matter content in the samples as well as a higher presence of volatile non-biodegradable materials such as plastics in MSW samples.

As observed in Table 2, GB and BMP values gradually decreased at each stage of the waste treatment plant showing the efficiency of the different processes used to stabilize the biodegradable organic matter present in the fresh materials, as it has been recently observed.[8]

Biogas and methane potentials at different periods of time

From the results presented in the previous section, it can be concluded that the accurate determination of the total biogas or methane potential of an OFMSW or MSW sample requires periods of time of up to 100 days. The disadvantages of such a long analysis are obvious for plant monitoring and design. To overcome this problem, values of biogas potential of all the samples obtained at different times were examined to test if a shorter period of time could be representative of the overall biogas production.

Table 3 shows the correlations found for the biogas potential obtained at 3, 4, 5, 6, 7, 14, 21, 50 and 100 days of analysis for the OFMSW samples at different stages of biodegradation. As observed, all GB values correlated well (p values below 0.002 in all cases). According to Table 3, GB_{14} accounts for the 64% of total biogas potential, GB_{21} represents the 77% and GB_{50} is the 97%, respectively. It is worthwhile to mention that the total biogas and methane production from the OFMSW can be correctly estimated with only 3 days of testing.

In the case of mixed MSW samples (data not shown), the GB values determined after only a few days of analysis did not correlate well with the GB values obtained at longer periods. An explanation of this fact can be the inherent heterogeneity and variability of the composition of these samples. However, GB values tend to be similar at longer experimental times. In this regard, correlations of GB_{14}, GB_{21} and GB_{50} vs. GB_{100} are acceptable ($p<0.01$). For MSW samples, GB_{14}, GB_{21} and GB_{50} account for the 38%, 71% and 94% of the total biogas potential, respectively. It is particularly remarkable that the value at 14 days is only the 38% of the total biogas produced, whereas in the case of the OFMSW the biogas produced at 14 days accounted for the 64% of GB_{100}.

It must be highlighted that the fraction of total biogas potential produced during the same period of time is different for the two different types of wastes considered (OFMSW and MSW), being the disagreement higher for short times of analysis. This fact is interesting since it poses the problem that these materials can behave differently, although no data have been found in literature. Consequently, the amount of biogas produced with time should be investigated for each waste. Besides, from data of biogas production at different times, the retention time could be selected in full-scale anaerobic digestion.

The correlations obtained are valid for all the analyzed samples collected at different stages of biodegradation and can be considered general expressions suitable for process modeling or the estimation of the retention time in a full-scale anaerobic digestion process.

Acknowledgments

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Tables

Table 1: Codification and general characteristics of the samples analyzed (in brackets, processing time).

Sample codification*	Treatment
OF1	None
OF2	None
OF3	None
MSW1	None
MSW2	None
MSW3	None
OF-MPT	MPT
MSW-MPT1	MPT
MSW-MPT2	MPT
OF-AD1	MPT + AD (21 days)
OF-AD2	MPT + AD (21 days)
MSW-AD	MPT + AD (21 days)
OF-COM1	MPT + AD (21 days) + COM (2 weeks)
OF-COM2	MPT + AD (21 days) + COM (4 weeks)
MSW-COM1	MPT + AD (21 days) + COM (4 weeks)
MSW-COM2	MPT + AD (21 days) + COM (2 weeks)
MSW-COM3	MPT + COM (3 weeks)
MSW-COM4	MPT + COM (4 weeks)
MSW-LF1	Sanitary landfill (2 years)
MSW-LF2	Sanitary landfill (2 years)

*Codification used: OF: Organic Fraction of Municipal Solid Waste; MSW: Municipal Solid Waste; MPT: Mechanical Pretreatment; AD: Anaerobic Digestion; COM: Composting; LF: Sanitary Landfill.

Table 2: Biogas (GB) and methane potential (BMP) at 21 and 100 days, organic and dry matter content for the samples analyzed. Note that samples with the same codification but different number are samples of different origin, municipality, collection system and impurities content (not replications of the same sample). Each sample was analyzed in triplicate so data is presented as average with standard deviation.

Sample codification	GB_{21} (Nl biogas kg^{-1} DM)	GB_{100} (Nl biogas kg^{-1} DM)	BMP_{21} (Nl CH_4 kg^{-1} DM)	BMP_{100} (Nl CH_4 kg^{-1} DM)	Dry Matter Fraction	Volatile Solids Fraction
OF1	92 ± 33	270 ± 48	50 ± 18	148 ± 34	0.33 ± 0.04	0.87 ± 0.03
OF2	410 ± 60	575 ± 75	281 ± 38	385 ± 54	0.29 ± 0.06	0.78 ± 0.03
OF3	340 ± 40	372 ± 37	223 ± 8	245 ± 27	0.20 ± 0.04	0.88 ± 0.03
OF-MPT	224 ± 92	305 ± 26	125 ± 60	170 ± 19	0.40 ± 0.06	0.63 ± 0.03
OF-AD1	22 ± 7	51 ± 11	15 ± 4	32 ± 11	0.37 ± 0.02	0.50 ± 0.02
OF-AD2	98 ± 3	152 ± 5	59 ± 2	92 ± 3	0.26 ± 0.02	0.47 ± 0.02
OF-COM1	33 ± 12	68 ± 12	20 ± 8	41 ± 9	0.48 ± 0.01	0.47 ± 0.01
OF-COM2	48 ± 3	80 ± 5	28 ± 2	48 ± 3	0.49 ± 0.01	0.47 ± 0.02
MSW1	43 ± 10	129 ± 50	23 ± 5	79 ± 48	0.39 ± 0.02	0.86 ± 0.04
MSW2	156 ± 29	259 ± 128	91 ± 10	142 ± 82	0.39 ± 0.02	0.69 ± 0.05
MSW3	89 ± 7	128 ± 18	40 ± 3	66 ± 12	0.47 ± 0.02	0.57 ± 0.01
MSW-MPT1	221 ± 53	292 ± 57	130 ± 8	174 ± 34	0.30 ± 0.07	0.75 ± 0.02
MSW-MPT2	133 ± 20	207 ± 44	82 ± 12	127 ± 28	0.57 ± 0.03	0.50 ± 0.02
MSW-AD	120 ± 59	209 ± 90	73 ± 31	126 ± 53	0.18 ± 0.02	0.54 ± 0.03
MSW-COM1	47 ± 18	75 ± 20	27 ± 8	45 ± 14	0.49 ± 0.01	0.33 ± 0.02
MSW-COM2	64 ± 24	168 ± 21	41 ± 16	105 ± 12	0.56 ± 0.01	0.52 ± 0.02
MSW-COM3	97 ± 9	129 ± 15	64 ± 6	86 ± 10	0.71 ± 0.02	0.46 ± 0.03
MSW-COM4	81 ± 9	107 ± 14	54 ± 6	72 ± 9	0.83 ± 0.03	0.48 ± 0.02
MSW-LF1	73 ± 30	145 ± 40	48 ± 23	92 ± 25	0.56 ± 0.03	0.54 ± 0.06
MSW-LF2	120 ± 22	206 ± 36	74 ± 14	129 ± 23	0.51 ± 0.03	0.51 ± 0.02

Table 3. Correlations for biogas production obtained at different assay times for samples of the organic fraction of municipal solid waste. All the OFMSW samples analyzed in Table 2 are included in these correlations.

Y↓ X→	GB_3	GB_4	GB_5	GB_6	GB_7	GB_{14}	GB_{21}	GB_{50}	GB_{100}
	GB_3	0.79x+2.06 p<0.0001 R^2=0.990	0.65x+3.67 p<0.0001 R^2=0.974	0.54x+2.96 p<0.0001 R^2=0.973	0.52x+0.77 p<0.0001 R^2=0.979	0.45x-7.53 p<0.0001 R^2=0.948	0.36x-8.07 p=0.0003 R^2=0.905	0.31x-17.7 p<0.0001 R^2=0.970	0.30x-21.6 p<0.0001 R^2=0.953
		GB_4	0.82x+1.68 p<0.0001 R^2=0.996	0.69x+0.79 p<0.0001 R^2=0.994	0.66x-1.74 p<0.0001 R^2=0.992	0.57x-11.6 p<0.0001 R^2=0.943	0.45x-10.9 p=0.0008 R^2=0.867	0.39x-23.2 p=0.0005 R^2=0.938	0.37x-27.9 p=0.0002 R^2=0.918
			GB_5	0.84x-1.06 p<0.0001 R^2=0.998	0.80x-3.92 p<0.0001 R^2=0.990	0.68x-15.3 p=0.0001 R^2=0.928	0.53x-13.5 p=0.0016 R^2=0.833	0.46x-28.6 p=0.0012 R^2=0.845	0.44x-33.9 p=0.0005 R^2=0.887
				GB_6	0.95x-3.57 p<0.0001 R^2=0.996	0.82x-17.9 p<0.0001 R^2=0.948	0.64x-15.7 p=0.0011 R^2=0.851	0.55x-32.7 p=0.0002 R^2=0.911	0.53x-39.1 p=0.0005 R^2=0.888
					GB_7	0.87x-16.1 p<0.0001 R^2=0.967	0.68x-15.1 p=0.0004 R^2=0.891	0.56x-31.5 p=0.0001 R^2=0.928	0.56x-38.2 p=0.0003 R^2=0.905
						GB_{14}	0.80x-1.06 p<0.0001 R^2=0.952	0.67x-16.5 p<0.0001 R^2=0.939	0.64x-24.4 p=0.0002 R^2=0.919
							GB_{21}	0.81x-13.8 p=0.0001 R^2=0.928	0.77x-23.1 p=0.0003 R^2=0.904
								GB_{50}	0.97x-13.9 p<0.0001 R^2=0.997
									GB_{100}