Environment Protection Engineering

Vol. 38 2012 No. 4

DOI: 10.5277/EPE120413

MAGDALENA LEBIOCKA*, ADAM PIOTROWICZ*

CO-DIGESTION OF SEWAGE SLUDGE AND ORGANIC FRACTION OF MUNICIPAL SOLID WASTE. A COMPARISON BETWEEN LABORATORY AND TECHNICAL SCALES

The effect of adding of the organic fraction of municipal solid waste (OFMWS) on the anaerobic digestion of municipal sewage sludge (SS) has been examined. Research on a laboratory scale showed that the 75:25 ratio by volume of SS to OFMWS is the recommended limiting value which ensures effective co-fermentation and intensification of biogas production. Biogas production on the technical scale was significantly lower in comparison to that on the laboratory scale which could be the result of lower digester loads in the technical environment.

1. INTRODUCTION

In recent years, much has been said and written regarding climate change but a lot less about the fact that the main fossil fuels and non-renewable resources will become exhausted. Consequences of shortage of non-renewable resources could be much more severe than the greenhouse effect [1–3]. Development of modern civilization is highly unsustainable and appears to indicate that full sustainability is impossible. However, this does not mean that we cannot do anything about it. From a practical standpoint, the sustainability goal should be to minimize, as far as practical, the use of energy and the irreplaceable raw materials. We should also seek energy sources and materials which are replaceable or self-regenerating and as non-polluting as practically possible [4, 5]. What is crucial to this relationship is an increase in the role of ethics in the functioning of contemporary social-economic systems [6–8], especially consumption driven by commercials [9], and to increase the awareness of threats through education on all levels of changes in the quality of life criteria [10, 11], with special attention to

*Faculty of Environmental Engineering, Lublin University of Technology, ul. Nadbystrzycka 40B, 20-618 Lublin, Poland; corresponding author M. Lebiocka, e-mail: m.lebiocka@wis.pol.lublin.pl

environmental services [12]. One such possibility in waste management is to change the practice of depositing in landfills to a waste-to-energy approach. During anaerobic digestion, organic fraction in sewage sludge (SS) is reduced to 40–70%, generating biogas (containing methane and carbon dioxide) as a product. Co-digestion of organic fraction from the municipal solid waste (OFMSW) and the SS allows the energy to be recycled in the form of biogas, which is in accordance with the rule of sustainable development [13, 14–21].

Advantages of the co-fermentation process [22, 23] are as follows:

- dilution of toxic substances present in substances subjected to co-fermentation
- a higher biogas production
- a more profitable C:N ratio

Co-digestion of SS and OFMSW is more beneficial than classic arrangement of anaerobic fermentation, not only because of the increase in biogas production, but also due to the possibility of limiting landfill methane emissions “at source”.

2. MATERIALS AND METHODS

Laboratory experiments were conducted using two model reactors, each with an active volume of 40 dm^3, for the anaerobic digestion of sewage sludge. The reactors worked in a quasi-flow system at a constant temperature of 35 °C with continuous mixing. The fermentation period was between 18 and 20 days.

The sewage sludge used in the experiments was obtained from a wastewater treatment plant in Puławy (in Lublin Voivodeship, Eastern Poland), with the primary and waste sludge mixed in a 60:40 ratio by volume. The OFMSW was obtained from a municipal solid waste landfill in Puławy and made into a pulp through the addition of landfill leachate.

Two reactors (R1, R2) were used. Reactor R1 was fed with 100% SS, whilst reactor R2 was fed with two mixtures of SS and OFMSW: 75:25 and 70:30 by volume. Biogas production and the methane concentration in the biogas were analysed during the experiments [24]. Table 1 shows characteristics of the samples.

The above results were verified on the technical scale by means of two digesters of the total active volume of 5000 $m^3 \cdot d^{-1}$, working under mesophilic conditions (35 °C), and a fermentation period ranging from 20 to 30 days, depending on the daily SS production and OFMSW addition.

The sample materials were

- thickened SS (primary and waste sludge) with ratios ranging from 35:65 to 71:29 by volume. The ratios were adjusted during the research period to cater for the variability in the amount of SS produced.
- OFMSW, gathered from the Puławy landfill site.

Table 1

Digester influent and effluent characteristics during the experiments

Parameter	Reactor R1 SS 100%		Reactor R2 SS 75% + OFMSW 25%		Reactor R1 SS 100%100%		Reactor R2 SS 70% + OFMSW 30%	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	6.38	7.70	6.30	7.75	6.27	7.79	6.21	7.83
Alkalinity, $mg \cdot dm^{-3}$	995	3528	1759	3828	1070	3338	1964	4010
COD, $mg \cdot dm^{-3}$	41748	23553	35439	20331	42388	23701	34652	17705
COD_{sol}, $mg \cdot dm^{-3}$	2676	1612	4320	1221	3018	1550	4888	1305
VFA, $mg \cdot dm^{-3}$	1619	235	2286	187	2027	225	3126	290
Total solids, $g \cdot kg^{-1}$	36.6	25.2	32.0	23.4	36.8	25.1	29.9	20.9
Volatile solids, $g \cdot kg^{-1}$	27.4	16.5	23.3	14.2	27.4	16.2	21.5	12.3
$N\text{-}NH_4^+$, $mg \cdot dm^{-3}$	86	542	139	541	88	442	158	451
$P\text{-}PO_4^{3-}$, $mg \cdot dm^{-3}$	113	124	91	80	116	117	dm–390	61

During the initial five month period (phase 1), the efficiency of the SS anaerobic digestion process, without the addition of OFMSW, was analysed by measuring the production of biogas and the concentration of methane within it. Over the next seven months (phase 2) similar measurements were taken for the SS+OFMSW co-fermentation process. The percentage share by volume of the OFMSW in the digester feedstock ranged between 6 and 23%, with an average for the research period being 12.2%.

3. RESULTS AND DISCUSSION

On a laboratory scale, addition of OFMSW to fermenting SS may lead to an increase in biogas production. It was shown that the 75:25 SS to OFMSW by volume ratio is optimum, assuring effective co-fermentation and increase in biogas production. In turn, the effects obtained using a higher OFMSW proportion (ca. 30%) are comparable with those obtained during fermentation of SS without addition of OFMSW [9]. Figure 1 shows the average biogas production figures per kg of the removed substrate with 75:25 and 70:30 SS to OFMSW by volume ratios.

It was found that the addition of 25% OFMSW increased biogas production by an average of 24.8% per kg of volatile solids (VS), 36.6% per kg of removed total solids (TS), and 35% per kg of removed chemical oxygen demand (COD), relative to SS fermentation. The addition of 30% OFMSW did not increase biogas production. Its production was similar to that obtained during SS fermentation. A similar trend was observed in biogas production recalculated with respect to substrate placed in the bioreactors. This production amounted to 0.39–0.41 $m^3 \cdot kg^{-1}$ VS when SS was fermented, 0.54 $m^3 \cdot kg^{-1}$ VS when the SS to OFMSW volume ratio was 75:25, and 0.45 $m^3 \cdot kg^{-1}$ VS when this ratio was 70:30. The percentage of methane in the biogas generated during co-digestion was 53.8% for the 75:25 SS to OFMSW ratio and 54.7% for the 70:30 ratio. The percentage of methane in the biogas generated during SS fermentation was 55.8% for the 75:25 SS to OFMSW ratio and 56.7% for the 70:30 ratio. The methane yields per kg of removed substrate for 25% OFMSW were 0.81 m^3 $CH_4 \cdot kg^{-1}$ VS, 0.96 m^3 $CH_4 \cdot kg^{-1}$ TS, and 0.52 m^3 $CH_4 \cdot kg^{-1}$ COD. During SS, fermentation the corresponding values were 0.68 m^3 $CH_4 \cdot kg^{-1}$ VS, 0.74 m^3 $CH_4 \cdot kg^{-1}$ TS, and 0.40 m^3 $CH_4 \cdot kg^{-1}$ COD, respectively.

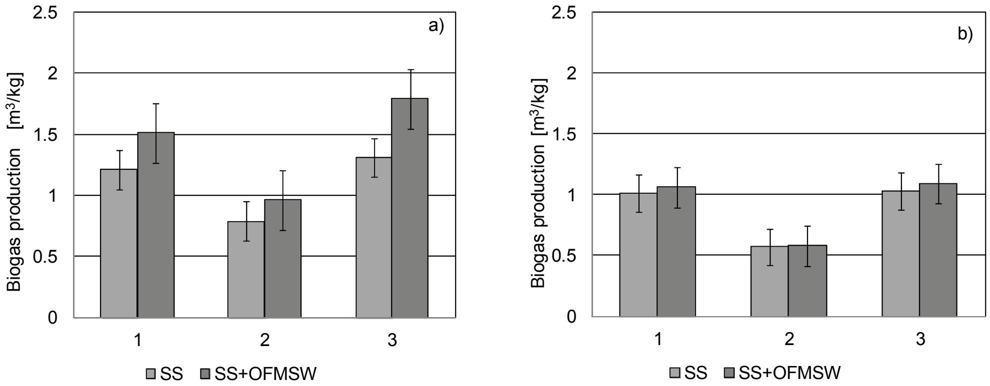

Fig. 1. Biogas production per kg: 1 – VS_{rem}, 2 – COD_{rem}, 3 – TS_{rem}; a) phase 1, 75:25 SS to OFMSW by volume ratio, b) phase 2, 70:30 SS to OFMSW by volume ratio

The increase in methane production during co-digestion using 25% OFMSW was 19.1% per kg of removed volatile solids, 30% per kg of removed total solids and 29.7% per kg of removed COD in comparison to SS fermentation.

Under technical conditions, when OFMSW was added to the digesters, an increase, relative to SS fermentation, in biogas production was observed (Fig. 2).

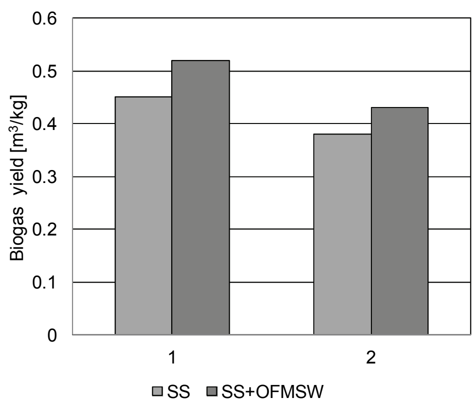

Fig. 2. Biogas production per kg: 1 – VS_{rem}, 2 – TS_{rem} obtained on the technical scale

This growth was 15.6% per kg of organic matter removed in the reactors and 13% per kg of removed dry mass, respectively. Biogas production, per kg substrate inserted into the digester, was 0.27 $m^3 \cdot kg^{-1}$ VS in phase 1 and 0.31 $m^3 \cdot kg^{-1}$ VS in phase 2. The biogas yields on the technical scale (1.02 and 0.94 kg $VS \cdot m^{-3} \cdot d^{-1}$ in phase 1 and in phase 2, respectively) were significantly lower in comparison with those obtained in the laboratory, which could be the result of low digester loading with organic matter. In phase 1 of the experiment, the percentage of methane in the biogas was 12% per kg of removed organic substances and 9.5% per total solids removed, whilst in phase 2, it was lower on average by about 1.8% with reference to phase 1. The methane yields in phase 1 (without OFMSW) were 0.25 m^3 $CH_4 \cdot kg^{-1}$ VS and 0.21 m^3 $CH_4 \cdot kg^{-1}$ TS, while in phase 2 they were 0.28 $CH_4 \cdot kg^{-1}$ VS and 0.23 m^3 $CH_4 \cdot kg^{-1}$ TS, respectively. An analysis of the anaerobic digestion process showed a high efficiency in the removal of organic matter, reaching 61% in phase 1 and 64% in phase 2. This could be explained by cubature oversizing of the digesters and very long fermentation periods of 39.2 and 31.7 days for phases 1 and 2 respectively. The addition of OFMSW caused a reduction in the fermentation period, however the active capacity of the digestion chambers was still too big and the chamber loading too small.

4. CONCLUSIONS

Research in the laboratory showed that the 75:25 SS to OFMSW by volume ratio is the recommended limit which ensures effective co-fermentation and intensification of biogas production. The addition of 25% OFMSW increases biogas production from 1.21 to 1.51 $m^3 \cdot kg^{-1}$ VS_{rem}, 0.79 to 0.96 $m^3 \cdot kg^{-1}$ TS_{rem} and 1.31 to 1.79 $m^3 \cdot kg^{-1}$ COD compared with pure SS fermentation. Addition of 30% OFMSW did not result in more efficient biogas production, and the indicator values were comparable with those obtained during SS fermentation, potentially caused by disturbing the C:N proportions. Simulations show that it is possible to predict biogas and methane production for SS and OFMSW mixtures. Research into the technical scale indicates that the addition of OFMSW increases biogas production by 15.6% per kg of VS and 13.2% per TS on average, in comparison to SS fermentation. The amount of methane in the biogas obtained as a product of co-fermentation is about 1.8% lower compared with SS fermentation.

Co-digestion of SS and OFMSW in proportion of 12.2% on the technical scale leads to methane production of 0.28 m^3 $CH_4 \cdot kg^{-1}$ VS and 0.23 m^3 $CH_4 \cdot kg^{-1}$ TS, while SS fermentation produces only 0.25 m^3 $CH_4 \cdot kg^{-1}$ VS and 0.21 m^3 $CH_4 \cdot kg^{-1}$ TS. Biogas and methane yields on the technical scale are significantly lower than in the laboratory, which could be due to lower digester loads. The digestion chambers in the municipal wastewater treatment plant in Puławy are oversized. They work with too small volume and organic loads. In addition, the fermentation period exceeds 30 days, which indicates the possibility of introducing additional components for co-digestion.

REFERENCES

[1] LINDZEN R.S., Probl. Ekorozw., 2010, 2 (5), 13.
[2] DASGUPTA P., TANEJA N., Probl. Ekorozw., 2011, 6 (1), 64.
[3] HOEDL E., Probl. Ekorozw., 2011, 6 (2), 11.
[4] SOSNOWSKI P., KLEPACZ-SMOLKA A., KACZOREK K., LEDAKOWICZ S., Bioresource Technol., 2008, 99, 5731.
[5] VENKATESH G., Probl. Ekorozw., 2011, 6 (2), 63.
[6] KEITSCH M., Probl. Ekorozw., 2011, 6 (2), 19.
[7] ROŻNOWSKA A., Probl. Ekorozw., 2011, 6 (2), 127.
[8] VENKATESH G., Probl. Ekorozw., 2010, 2 (5), 29.
[9] DAVIS R., Probl. Ekorozw., 2010, 1 (5), 15.
[10] ZECHA G., Probl. Ekorozw., 2011, 6 (1), 47.
[11] KRONENBERG J., IIDA N., Probl. Ekorozw., 2011, 6 (2), 67.
[12] MICHAŁOWSKI A., Probl. Ekorozw., 2011, 6 (2), 117.
[13] MONTUSIEWICZ A., LEBIOCKA M., PAWŁOWSKA M., Arch. Environ. Prot., 2008, 34 (3), 49.
[14] PAWŁOWSKA M., SIEPAK J., PAWŁOWSKI L., PEŁCZYŃSKI J., Patent nr EP08165556.5, 2008.09.05.
[15] PAWŁOWSKI L., MONTUSIEWICZ A., POLESZAK A., DUKLEWSKI W., JAŚKOWSKI R., Patent nr EP10197094.5, 2009.12.27.
[16] PAWŁOWSKA M., SIEPAK J., *Polish Environmental Engineering Five Years after Accession to European Union*, [in:] M. Dudzińska, L. Pawłowski (Eds.), *Monographs of the Committee of Environmental Engineering*, 2009, 60, 191–198 (in Polish).
[17] PAWŁOWSKA M., SIEPAK J., *Enhancement of Methanogenesis at a Municipal Landfill Site by Addition of Sewage Sludge*, Proc. 2nd Congress of Environmental Engineering, Lublin, 4–7.09.2005, 1221–1228 (in Polish).
[18] PAWŁOWSKA M., SIEPAK J., Environ. Eng. Sci., 2006, 23 (4), 673.
[19] STASZEWSKA E., PAWŁOWSKA M., Environ. Prot. Eng., 2011, 37 (4), 119.
[20] CAO Y., PAWŁOWSKI A., Environ. Prot. Eng., 2012, 38 (2), 77.
[21] UDO V., PAWŁOWSKI A., Probl. Ekorozw., 2011, 6 (2), 33.
[22] CECCHI F., PAVAN P., MATA-ALVAREZ J., Resour. Conserv. Rec., 1996, 17, 57.
[23] PAWŁOWSKA M., SIEPAK J., PAWŁOWSKI L., PEŁCZYŃSKI J., Patent nr EP08165558.1, 2008.09.05.
[24] MONTUSIEWICZ A., *Co-digestion of sewage sludge and selected components as a method of effective biomethanization*, Monographs of the Committee of Environmental Engineering, Polish Academy of Sciences, Vol. 98, Lublin, 2012 (in Polish).